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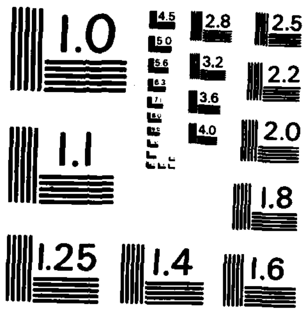
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DECISION SUPPORT SYSTEMS: AN APPROACH TO AIRCRAFT MAINTENANCE SCHEDULING IN THE STRATEGIC AIR COMMAND

Stephen B. Hackett, First Lieutenant, USAF
Sam E. Pennartz, Captain, USAF

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Maintaining increasingly complex Air Force weapon systems requires optimum use of all available resources. Timely and accurate resource coordination is vital to ensure continuous mission capability; any improvement in coordination can produce an increase in readiness. Essential to such resource coordination is the aircraft maintenance scheduling function at the unit level. It is hypothesized that the application of computer technology to the maintenance scheduling decision process could result in improved maintenance resource allocation. A promising tool for computer-aided scheduling exists; Decision Support Systems (DSS) are intended to combine the information storage and assimilation powers of the computer with the experienced judgement of the manager to produce more effective decisions. The first requirement of a DSS is to model the current decision process; this research effort has generated a maintenance scheduling model of a SAC wing-level organization. The architecture of the model is based on Integrated Computer-Aided Manufacturing (ICAM) technology, specifically incorporating the structure explained in the ICAM Definition ($IDEF_0$) Function Modeling Manual. The model should lead to DSS implementation and an expansion of applications to other Major Commands, scheduler training, and to enhanced communication between maintenance managers.

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DECISION SUPPORT SYSTEMS: AN APPROACH TO AIRCRAFT MAINTENANCE SCHEDULING IN THE STRATEGIC AIR COMMAND

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

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This thesis, written by

First Lieutenant Stephen B. Hackett

and

Captain Sam E. Pennartz

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

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CHAPTER I

INTRODUCTION

Overview

The United States Air Force mission of national defense demands optimum use of all available resources. Air Force managers are constantly searching for more efficient techniques to assure the timely distribution of resources and to maximize military defense capability. In a large organization, such as the Air Force,

> . . . relatively small improvements in resource allocation efficiency could produce striking amounts of absolute dollars either saved or turned to increased performance [Berman, 1975:2].

This is especially significant in the process of maintaining complex aerospace weapons systems. Maintaining Air Force materiel in a more serviceable condition produces increased degrees of readiness. Readiness is directly related to the Air Force mission of national defense. The key to mission success is the sustained ability to provide safe, reliable, and properly configured equipment at the time and place it is needed (USAFR 66-1, Vol.1, 1980:p.1-1). Since such sustained capability results from the coordination among many agencies, an improvement in coordination can produce an increase in readiness. This research deals with one such coordinating agency: the Plans and

Scheduling staff function of the Deputy Commander for Maintenance (DCM) complex in a wing level aircraft maintenance organization.

Maintenance Responsibilities and Management Procedures

Air Force Regulation 66-1, Volume 2, entitled Maintenance Management: Aircraft Maintenance (Deputy Commander for Maintenance), specifies the maintenance responsibilities and management procedures for the DCM and his staff. This organizational framework provides a basis for understanding the responsibilities of the Plans and Scheduling function and the nature of its contribution to the wing combat effectiveness and efficiency in mission performance.

DCM Scheduling Complex

The DCM is assigned the responsibility to "plan, schedule, control, and direct the use of all maintenance resources to meet mission requirements [USAFR 66-1, Vol.2, 1980:p.1-1]." This responsibility is accomplished through the use of the staff and line functions depicted in Figure 1-1.

One staff function, Maintenance Control, manages the maintenance line production by providing centralized planning, scheduling, directing, and controlling of all maintenance actions. One of the functional elements of

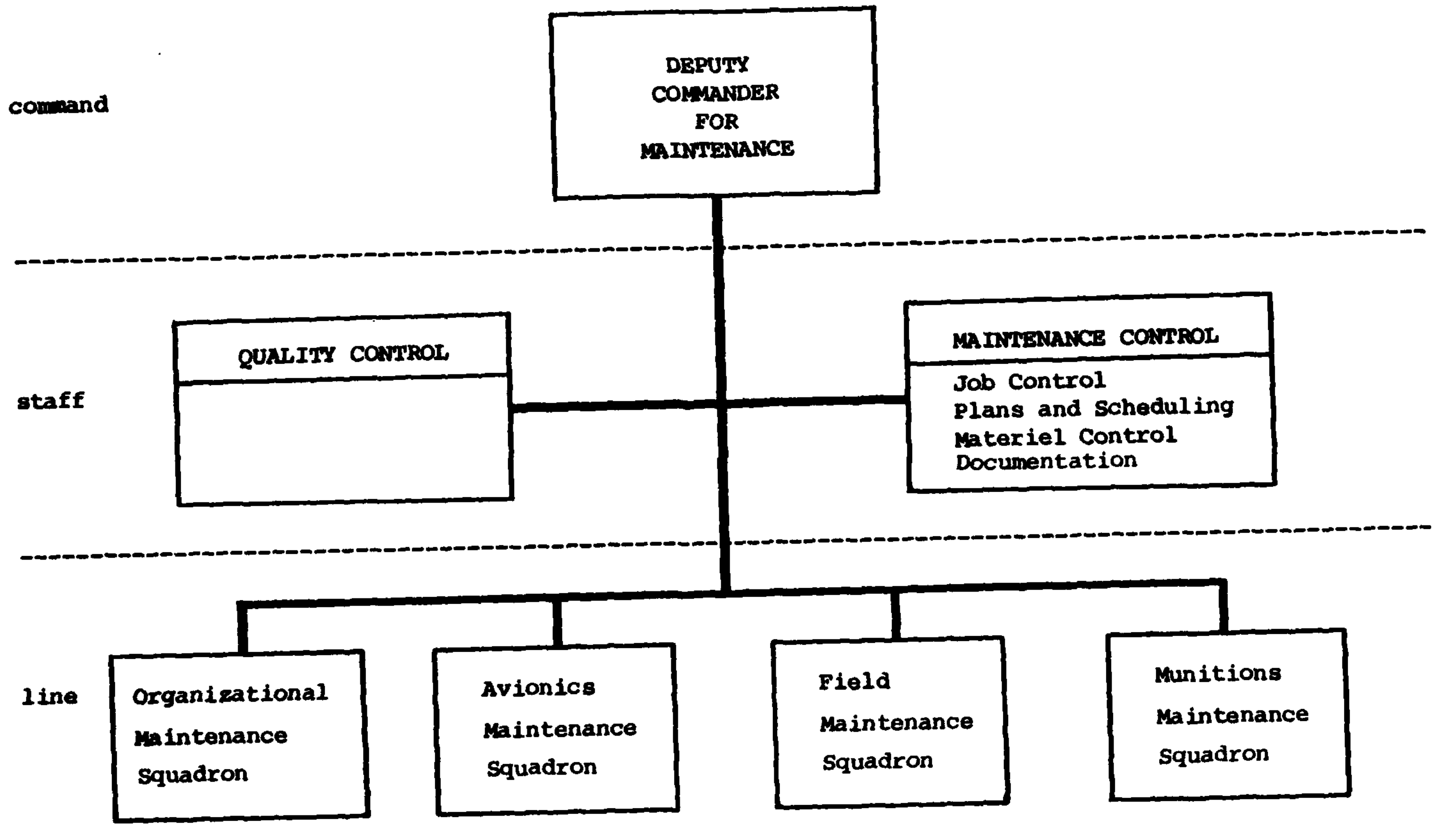


Fig. 1-1. Typical AFR 66-1 Maintenance Organization

Maintenance Control is the Plans and Scheduling work center.

Scheduling equipment and personnel for certain tasks at specific times is an important process for maintenance managers. Maintenance managers assigned to Plans and Scheduling normally are cross-trained from related maintenance career fields. They receive six to eight weeks of specialized maintenance management training. This technical training provides each scheduler with entry level knowledge of maintenance plan development, and a design for scheduling aircraft and equipment. Some of their planning and scheduling responsibilities are (USAFR 66-1, Vol.2, 1980:2-11):

> a. Plans and schedules the use and maintenance of aerospace vehicles, aircrew training devices, and equipment to meet mission and maintenance training commitments.
> b. Ensures, in conjunction with the analysis functions, that the maintenance control supervisor and the deputy commander for maintenance are advised of maintenance capability, problem areas, and adherence to schedules. . . .
> e. Schedules aircraft and related equipment through all phases of maintenance.
> f. Schedules munitions loading of aircraft to meet operational schedules and schedules munitions loading crew training requirements in conjunction with the munitions activity. . . .
> k. Incorporates munitions maintenance activity bulk scheduling requirements for direct aircraft support into the monthly maintenance plan.
> l. Preplans requirements for emergency war order or contingency plans, operational launch schedules, and prelaunch maintenance and loading requirements as required by unit mission. . . .
> n. Develops maintenance plans to include monthly and weekly plans as a minimum, and those specialized plans required by the DCM.

o. Conducts the daily maintenance planning meeting to confirm the daily portion of the weekly maintenance plan and the workload requirements.
p. Maintains programmed depot maintenance and other depot level maintenance program schedules in support of major command plans and requirements.
q. Schedules and conducts all maintenance scheduling meetings in coordination with necessary activities.
r. Reviews the weekly and monthly training schedule to minimize impact on production and facilitate use of aircraft and equipment for maintenance training requirements.

These selected responsibilities have a direct impact on the operational planning cycle diagrammed in Figure 1-2. This cycle involves both operations and maintenance. To understand the aircraft maintenance scheduling process it is necessary to discuss this cycle.

Operational Planning Cycle

The operational planning cycle is intended to fully support the wing's mission and "to ensure optimum use of aerospace vehicles, aircrew training devices and equipment [USAFR 66-1, Vol.2, 1980:p.2-12]." Operational requirements and maintenance capabilities form the basis for development of unit schedules (SACR 60-9, 1980:p.1-1).

Unit planning is done on a quarterly basis and is refined monthly, weekly, and daily. The quarterly planning begins when the Deputy Commander for Operations receives the Flying Program Document. This document specifies the sortie requirements and flying hour allocations.

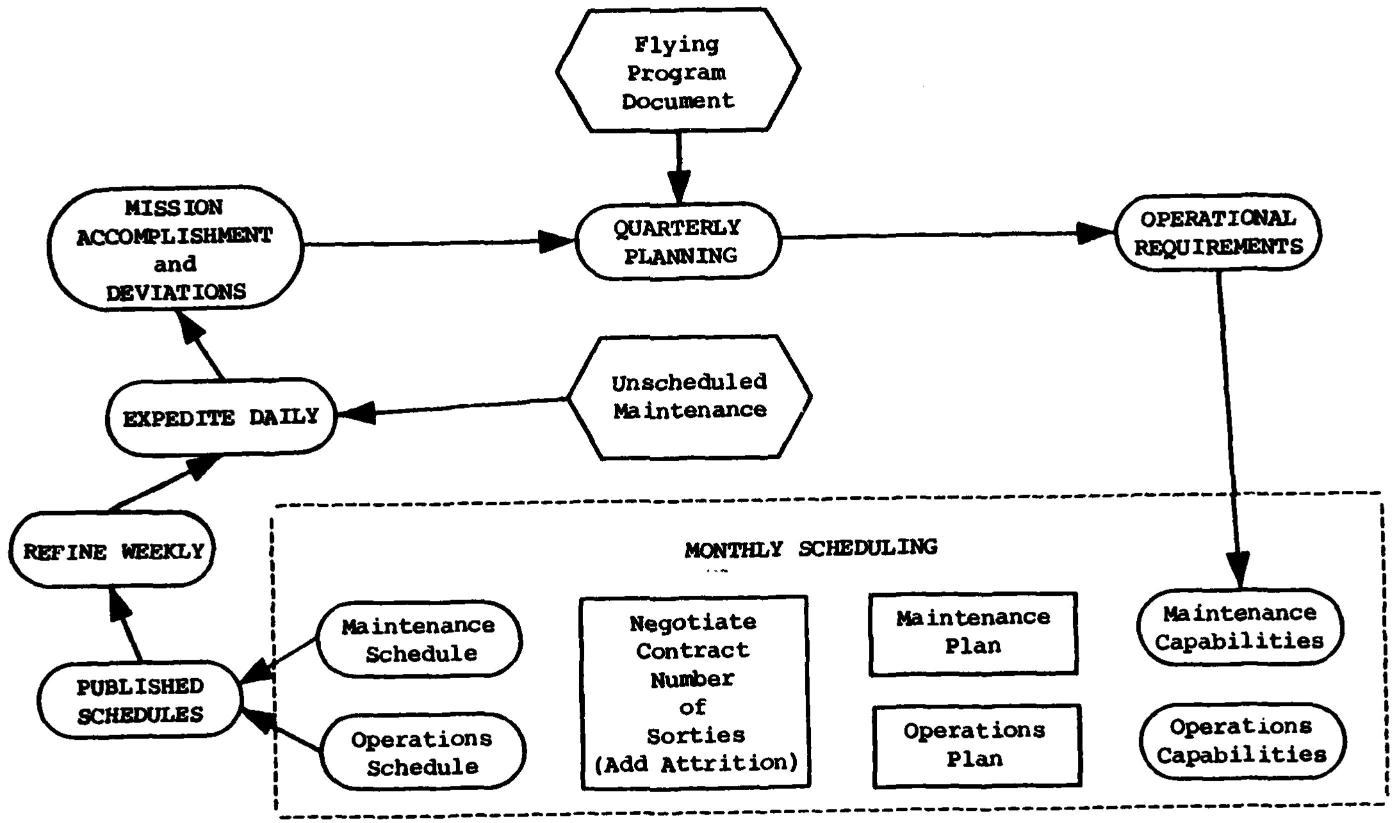


Fig. 1-2. Operational Planning Cycle

> The Deputy Commander for Maintenance must review these requirements, project the capability to support them, and notify operations when limitations exist [USAFR 66-1, Vol.2, 1980:p.2-12].

The key to quarterly planning and a good unit maintenance schedule is monthly planning. The monthly planning process contains the following sequence of events:

1. Operations provides maintenance with the estimated operational requirements.

2. After computing maintenance capability the Deputy Commander for Maintenance must notify operations that: (a) requirements can be met, (b) adjustments may be required, or (c) limitations exist.

3. Monthly planning is formalized at a combined operations and maintenance planning meeting.

> Plans and Scheduling must negotiate with the operations scheduling function to produce a contract which makes the most efficient use of resources [USAFR 66-1, Vol.2, 1980:p.2-12].

This contract contains a negotiated number of sorties that maintenance must provide aircraft for. Operations outlines past accomplishments, the degree to which mission goals are being met, problems being encountered, and detailed requirements for the coming month. Then maintenance presents projected capability, aircraft or equipment availability, and any expected overtime.

4. The wing commander decides what portions of the mission must be supported and when maintenance capability and operational requirements do not match.

5. A reasonable amount of attrition is added to the contract. The attrition factor is a historical estimate based on events which adversely affected previous mission accomplishment.

> The contract figure plus the attrition factor provide the basis for the development of the monthly maintenance plan and operations schedule [USAFR 66-1, Vol.2, 1980:p.2-13].

Deviations from this schedule must be held to a minimum, since it plays a major role in determining maintenance scheduling effectiveness. That is, was a maintenance action started and completed as scheduled? Such deviations from the schedule occur as either deletions or additions. Deletions are cancellations by operations or maintenance for any reason. Additions are sorties that are in excess of the schedule. "Both operations and maintenance share responsibility for monitoring and controlling deviations from the published schedule [USAFR 66-1, Vol.2, 1980: p.2-13]." Deviations are documented and analyzed to provide feedback to improve future scheduling and mission accomplishment. Therefore, the relative success of the operational planning cycle is partly affected by the quality of maintenance planning.

Maintenance Planning

Expert maintenance planning is "mandatory to ensure proper and effective use of maintenance resources [USAFR 66-1, Vol.2, 1980:p.2-13]." Maintenance planning

consists of long-range, monthly, weekly, and daily planning.

> Long-range planning is needed to support future requirements such as quarterly flying hour programs, programmed depot maintenance schedules, time compliance technical order programs, quality control activity inspections, and scheduled exercises [USAFR 66-1, Vol.2, 1980:p.2-13].

Plans and Scheduling forecasts and monitors projected requirements through the use of a conceptual plan that provides information for the current and next two months' requirements. Monthly scheduling is based on the operational requirements and maintenance capabilities agreed to at the operations/maintenance scheduling meeting. Weekly planning refines the monthly schedule and daily planning is the final adjustment.

Unit maintenance planning also involves the consideration of certain maintenance factors. Some of these maintenance planning factors are identified in USAFR 66-1 (Vol.2, 1980:p.2-14): aircraft flying hours, sorties, flightline and shop work schedules, alert requirements, time compliance technical orders, engine changes, time change items, depot maintenance, phase inspections, corrosion control, and configuration requirements (e.g., munitions, photo, and electronic countermeasures). Berman (1974:92-93) identified ten major factors the maintenance scheduler must contend with in maintenance planning. These may be considered planned events:

1. A certain percentage of aircraft must be "on alert" (aircraft parked near the end of a runway, loaded with weapons, and maintained in a ready state for quick access and launch by aircrews) in approximately ninety-day intervals.

2. Every 200 flying hours each SAC aircraft is to enter a comprehensive inspection of major systems, called a phase inspection. Only one phase dock (aircraft hangar or specialized maintenance facility) is available for each aircraft type (e.g., B-52, KC-135).

3. Every ninety days each aircraft is to undergo cleaning and other actions to prevent corrosion damage. One facility is typically shared by both B-52 and KC-135 aircraft.

4. Periodically extraordinary inspections (special inspections) of certain systems are directed by higher logistic echelons.

5. Time Compliance Technical Orders (TCTOs) are required for component modifications made to specific systems. The organization has a specified period of time to complete the TCTOs on each aircraft.

6. Prior to each sortie each aircraft is inspected to ensure that it is ready for flight.

7. Following each sortie the aircraft is recovered and inspected to disclose any malfunctions that may have occurred.

8. At specified intervals special actions are required on certain aircraft systems. These include engine changes, firing the guns, cleaning fuel cells, etc.

9. Every aircraft in the fleet is programmed for depot level maintenance at specific intervals. The aircraft undergo overhauls, modifications, and other actions requiring a specialized industrial plant.

10. Aircraft are used for the ground training of personnel (e.g., munitions load training).

Schedulers must actively consider these maintenance factors, other staff function inputs to maintenance planning, and proven scheduling techniques. This is the only way in which the maintenance workload can be effectively dealt with (USAFR 66-1, Vol.2, 1980:p.2-14).

Maintenance Scheduling

Maintenance scheduling is a complex process requiring maintenance and operations schedulers to integrate large quantities of information, often with conflicting objectives. The maintenance scheduler's attention is focused on the support needs of the wing's aircraft and the maintenance resources to support those needs. Maintenance schedulers face a high degree of uncertainty concerning random aircraft component failure and the time required for repair. The scheduler also has to work within policy guidelines from Strategic Air

Command headquarters and is constrained by the limited availability of resources. His concentration has to be on the effective use of maintenance manpower and other resources. Since the focus of attention in operations is aircrew scheduling, a continuous series of negotiations must take place to produce a monthly schedule which will satisfy mission requirements within existing operations and maintenance capabilities. Weekly and daily adjustments to the schedule are made to compensate for unplanned events, which occur regularly.

The maintenance scheduler's ability to plan for both known and unknown events is hampered by what Berman sees as problems with the current scheduling system. Under the time constraints placed on them, schedulers are usually able to develop only one schedule. They have a limited window of visibility and cannot predict all of the long-term effects of their daily decisions. There is insufficient guidance for their decision making concerning the relative importance of these conflicting objectives. For example, to obtain a particular number of sorties for several consecutive days, a scheduler can either advance or defer entrance into a phase inspection or corrosion control. If he chooses to defer, the scheduler would gain in responding to an immediate sortie requirement but could lose the maintenance objective of timely inspections and level workload. Thus required maintenance will have been

delayed, compounding subsequent scheduling decisions. Each alternative entails costs to overall mission performance, but the scheduler is freqently not aware of the nature of these costs or their effect on scheduling effectiveness.

Another problem area involves the negotiation procedures between operations and maintenance. Both organizations have goals which often seem to conflict. Neither group

> . . . has the ability to explore more than one or two possible schedules, neither has perfect visibility over its own data, and since there are no performance measures of schedules it is difficult to tell what is a good compromise [Berman, 1974:11].

Successful scheduling also depends on the level of organizational cooperation between operations and maintenance. A low level of cooperation will reduce total mission performance. Both agencies will seek to achieve a schedule that will ease their workload, but each could be perceived as detrimental to the other. In practice, either extreme serves to reduce the mission capability.

Each of these problems reflects an imperfect information flow. If the right information were available to the schedulers and other decision makers at the right time, performance levels could certainly be expected to increase. Hoped-for improvement may be found in the application of decision support concepts to the scheduling process.

Recent Studies

Much research has been accomplished in the area of applying computer technology to maintenance scheduling. The Rand Corporation has sponsored numerous studies in this area. Kiviat understood that

> . . . it is possible to write a computer program to do most of the work in going from the schedule worksheet to the maintenance plan documents, as well as all of the record-keeping and order-cutting necessary for dispatching men and equipment to meet the schedule [Kiviat, 1965:9].

Kiviat separated maintenance activities into scheduled and unscheduled functions, relating them to mission-essential activities based on particular flying profiles. However, his approach required a standardized maintenance scenario for each type of flying profile, limiting its flexibility and responsiveness. His concept did include a key idea: a person could be part of the data loop

> . . . to fill the information gap created by the indefinite nature of some of the activities, and by the uncertainty and variability that affects schedules as time progresses [Kiviat, 1965:9].

VIMCOS II

In 1970 a program began at the Air Force Institute of Technology (AFIT) to investigate problems associated with Air Force scheduling techniques. A thesis written by Babbitt and Welch involved simulation of unscheduled aircraft maintenance operations. The method employed was an "extension of an interactive game simulation developed

by Miller at Rand entitled VIMCOS II [Babbitt and Welch, 1970:2]." VIMCOS is an acronym for "Vehicle for the Investigation of Maintenance Control Systems." The game requires the player to schedule maintenance operations based on thirteen options. The authors expanded the basic model to provide a capability to estimate the length of jobs, making the simulation more realistic. Still, the flexibility of the game is limited and Miller recommended that future simulations on this scale be designed for more compatible computer systems, with increased core memory and enhanced ability to manipulate character strings (Babbitt and Welch, 1970:5).

The capabilities and limitations of VIMCOS II were brought out in more detail in a 1973 Rand report by Miller. He stated that

> . . . some caution is required in viewing VIMCOS II as a prototype maintenance scheduling system because it was designed around a particular scheduling problem [Miller, 1973:9].

Instead, he believed that the game could be especially useful because it highlights scheduling decisions and does not require a massive data base. The belief that only a person can evaluate subjective inputs is again mentioned. Miller admitted that the operator is not provided this role in the VIMCOS II game but "there is need for it in the real-world maintenance system [1973:33]." The closest the VIMCOS II model comes to this type of interaction is

by providing two options which let the computer assemble trial schedules. The operator then directs the computer through possible solutions, making judgements concerning those possibilities which seem to improve performance. Miller asserts that "by making the machine work harder with VIMCOS II, we actually increase the involvement of the man doing things that he can do best [1973:35]."

BOMS

Other computerized scheduling systems have been developed by Rand. One model reported by Miller and others in 1974 attempted to minimize aircraft down time by using various priority assignment procedures. It was based on the Base Operations-Maintenance Simulation (BOMS) model and is referred to by Miller et al. as Little BOMS. This was essentially a laboratory test and is stated to be an oversimplification, but the authors believed that many highly complete models are inadequate

> . . . for providing insights and exploring first-order effects. They have large appetites for data and computational resources, and so much is going on in them that it is difficult to analyze results [Miller et al., 1974:24].

This idea of simplification is similar to Miller's design in VIMCOS II, which was to provide "a more abstract and simpler model of the real world [1974:2]," than its predecessor VIMCOS.

L-COM

Paralleling the development of these models, Rand, in conjunction with the Air Force Logistics Command (AFLC), had produced the Logistics Composite Model (L-COM). It differs from the other models discussed in that it has been validated through application in an operational environment (Drake et al., 1970:1.2; L-COM, 1973:1-4). One advantage of L-COM is that the user can focus on a particular area of interest, such as the support system--or the operations aspect, and deemphasize other areas. In an AFIT master's thesis, Boyd and Toy used the L-COM model to test weekly flying schedules in the Tactical Air Command (TAC) in order to simulate weekly mission effectiveness. Their results showed that

> . . . although L-COM failed to satisfactorily predict the mission effectiveness of schedules on a weekly basis, it appeared quite able to predict the overall mission effectiveness of a series of schedules [Boyd and Toy, 1975:61].

They point to a need for further research on the monthly planning cycle and to extending the L-COM simulation time required to produce a more reliable estimate of mission effectiveness. However, Drake states that computerized simulation is

> . . . the most direct approach for considering the stochastic nature of the support processes in determining a best mix resource level that would effectively support a given weapon system flying program [1970:1.1].

DOSS

In a later report for Rand, Berman demonstrates "the even more difficult problem, which goes beyond simple manipulation of data, of dealing with a complex set of competing objectives [1974:61]." A need exists for better scheduling tools to facilitate the objective tradeoffs that are constantly being required of both aircrew and aircraft schedulers, in operations and maintenance. If decision makers had a method to observe different schedules and vary "the importance of achieving different objectives they would be better equipped for understanding the effects of different decisions upon the schedule [Berman, 1974:61-62]." To meet this need, Berman introduces a prototype of a Decision-Oriented Scheduling System (DOSS). His concept of an ideal DOSS is that it should provide five basic functions (Berman, 1974:65-66):

1. Maintain historical data on aircraft and aircrews.

2. Display measures of performance of the wing as a result of activities performed.

3. Allow detailed projections of the effects of future schedules on performance measures.

4. Answer real time queries.

5. Prepare reports on a regular basis and perform basic computations.

In the maintenance arena, Berman focuses on scheduled maintenance, not on daily unscheduled actions and dispatching. He emphasizes that a DOSS should be flexible to adapt to changes in policy, and that it should have access to the organization's historical data base. He recommends a method of attaching weights to specific wing goals, providing

> . . . an opportunity for members of the decision coalition both to observe historical performance measures and to construct alternative schedules rapidly, according to preferences for goals [Berman, 1975:93].

The DOSS would search for schedules which provide the highest levels of these goal weights.

<u>Systems Dynamics</u>

Berman's prototype DOSS created a requirement to model the scheduling process in order to provide a vehicle for testing alternative schedules. In a 1978 AFIT master's thesis, Barnidge and Cioli accomplished this. Drawing on the System Dynamics methodology developed by Forrester (1961) and others, they first created a causal loop diagram of a wing-level scheduling process. Assuming that the interactions and relationships depicted are representative of a typical SAC wing, they computerized the model and tested various scenarios. The results showed the overall aircraft failure rate "to be the single-most sensitive variable in the conceptualized system [Barnidge and Cioli, 1978:251]."

Since Barnidge and Cioli, further research has been conducted in the area of operations aircrew scheduling, but a definitive model of the maintenance aircraft scheduling process does not exist. Maintenance scheduling procedures are included in these operations studies to the extent that they are required to fill what would otherwise be obvious gaps. However, this work does not provide a comprehensive picture of the effect of maintenance inputs to the scheduling process.

Problem Statement

Recent research has emphasized computerization of the maintenance scheduling process. However, the management of this process has not been greatly improved by these techniques. There is a need for a definitive model of the structure of the wing level maintenance scheduling process.

Justification

An efficient maintenance scheduling process contributes heavily to operational readiness; improvement in this process can result in an immediate increase in mission capability. The research accomplished in computer-assisted Air Force maintenance scheduling confirms the potential of following this approach. A definitive model of the structure of the maintenance scheduling process

would provide a basis for development of an effective computerized system for wing level aircraft scheduling.

Since there is reason to believe that a new approach to scheduling automation is needed, it is necessary to review the application of new techniques to the scheduling process. Chapter II will provide an essential background for the maintenance scheduling problem and address relevant decision-making systems which could lead to an effective solution approach.

CHAPTER II

BACKGROUND

Scheduling

"Scheduling is the allocation of resources over time to perform a collection of tasks [Graybeal and Pooch, 1980:2]." In production scheduling there is always a scheduler whose primary focus centers on timely allocation decisions for all production resources (Graves, 1979:2). The scheduler must be aware of the amount and type of resources available, and will have usually been given broad guidelines and goals to follow. His responsibility is the process of sequencing tasks and allocating resources to achieve the desired end results as effectively as possible.

Scheduling theories abound. Many researchers have created models for generalized laboratory situations and have attempted to expand them to fit real-world scheduling problems (Panwalker and Iskander, 1977:59). Essentially, these models can be divided into two groups: static and dynamic. Static models are based on the premise that the scheduling sequences do not change with the passage of time (Graves, 1979:6). Thus accumulated tasks are scheduled at fixed internals and sequences. The

dynamic models, conversely, are in a constant state of flux, requiring updated decisions and frequent priority changes (Panwalker and Iskander, 1977:46). Dynamic schedules must constantly change to accommodate new tasks and requirements.

Dynamic Job Shop

Dynamic scheduling models appear in ascending degrees of complexity. The more complex models deal with numerous processing stages and feature a choice of routings for a particular task (Graves, 1979:4). Most real-world situations, diverse and very complex, are best represented by the dynamic job-shop concept. The job-shop

> . . . is the most general production scheduling problem; here there are no restrictions on the processing steps for a task, and alternative routings for a task may be allowed [Graves, 1979:4].

Most models of this type have been used to determine the sequencing of a set of jobs performed on a number of machines using certain basic criteria. The criteria for the basic job-shop are summarized by Salvador (1978:270):

1. Each machine is continuously available; i.e., there is no inherent provision for shutdown or breakdown time.
2. Operation sequences are strictly ordered; i.e., for a given operation and job, there is at most one other operation that immediately precedes it, and at most one operation that immediately succeeds it.
3. Each operation can be performed by only one type of machine in the job-shop.

4. There is only one of each type of machine in the job-shop.
5. Operation preemption is not allowed; i.e., once an operation is started on a machine, it must be completed before a different operation can begin on that machine.
6. A job can be in process on at most one machine at any given time.
7. A machine can be processing at most one operation at any given time.

Optimization Models

Many researchers have modified these criteria to test variations of the basic job-shop model. Cho and Shani (1981:511-522) tried a preemptive schedule (tasks may be interrupted and later continued). Garey et al. (1978:3-21) attempted to construct an algorithm with performance guarantees. Lageweg et al. (1977:441-450) used an implicit enumeration technique. These researchers, and many others, concede that as the complexity of these problems increases, optimal solutions are harder to achieve (Garey, et al., 1978:3; Kiviat, 1965:448; Ullman, 1976:140). This pessimistic outlook is emphasized by Garey et al. (1978:2):

> In fact, all but a few schedule-optimization problems are considered insoluble except for small or specially structured problem instances . . . no efficient optimization algorithm has yet been found, and indeed, none is expected.

Heuristic Techniques

Because of this relative lack of success with optimization models, researchers have turned to heuristic

procedures which produce approximate but feasible solutins (Graves, 1979:14). The Gantt chart (Baker, 1974:4) was the first effective attempt to develop a visual approximation of resource allocation by arranging variable length blocks on a graph. Another technique establishes rules to decide the sequence in which jobs are picked for execution from the queue of jobs awaiting processing. "More sophisticated procedures involve adjustment of local schedules interactively as they are generated [Salvador, 1978:284]." Although many heuristic techniques have been developed, they still represent a suboptimal solution for large and complex scheduling problems (Baker, 1974:209).

At this level of complexity the traditional scheduling theories seem to break down. As the scheduling problem becomes dynamic, the information processing requirements become unmanageable and inefficient. The search for solutions has necessitated a new approach to decision making in the scheduling environment.

Decision Support Systems

The decision maker and the computer are emerging as the management team of tomorrow. This is largely due to rapid advances in computer technology in recent years and a corresponding change in the philosophy concerning the most appropriate means of effectively implementing

this technology. For many years organizations have attempted to consolidate and standardize their computerized information processing needs and functions. Two key terms resulting from these efforts are Electronic Data Processing Systems (EDP) and Management Information Systems (MIS).

Electronic Data Processing

The thrust of EDP has centered on the automation of clerical tasks. Data files were used as computer inputs to produce the required reports, billings, statements, etc. which had previously been accomplished manually.

> The boundaries of these jobs were relatively narrow and quite well defined. As EDP jobs evolved, they became larger and more integrated in order to provide increased efficiency and enhanced capabilities [Sprague and Watson, 1977:8].

Technology advances facilitated increased EDP applications, leading to expansion and integration of processing jobs. This evolution led to the realization that if automation could speed up clerical production, perhaps it could also be used to facilitate managerial decision making. Implementations of this concept have been referred to as Management Information Systems (MIS).

Management Information Systems

MIS have evolved around the premise that managerial effectiveness could be improved by automating the

managerial information reporting system.

> For the most part, the development of computer-based MIS has been directed to the structured and operational control level of decision making. Because these types of decisions are routine and repetitive, they require easily identifiable and retrievable information [Watkins, 1982:38].

Sprague and Watson define a MIS as consisting of three subsystems (1977:9).

1. The structural reporting system.
   a) Reports communicating with parties external to the organization
   b) Traditional internal managerial reports
2. The data base management system.
   a) Design, structure, and maintenance of the organizational data base
   b) A communication network for gathering data and updating the data base
   c) A data base inquiry system
3. The decision models system, for instance:
   a) Data analysis models
   b) Scheduling and allocation algorithms
   c) Simulation models for evaluating plans and alternatives

MIS development has had a major impact on the organizational reporting system, integrating the clerical EDP advances with improved managerial efficiency. However, the decision models system has proved to be difficult to integrate into the MIS. Most models

> . . . do not have an established data base, are not easily interfaced or combined, are not easily updated, [and] each model's output usually stands alone, not being used as an input to any other model [Sprague and Watson, 1977:10-11].

This suggests that the data base management system has not been fully developed or implemented to mesh with increasing MIS requirements.

DSS Development

By the early 1970s the traditional MIS approach began to seem insufficient to deal with the managerial problem of effective data assimilation and decision making.

> A system designed to improve management performance by supporting decision making must go further than just providing access to data in a quick and flexible way. It must provide a mechanism for the decision maker to interact with data and models in a convenient, supportive manner [Sprague and Watson, 1979:63].

This concept of an interactive system supporting managerial decision making has evolved into a new view of organizational information processing. By 1971 this view had come to be defined as Decision Support Systems (DSS).

Decision support systems are not intended to replace management information systems. The concept is intended to provide managers and decision makers with an interactive information processing system, resulting in more effective decisions. Keen and Morton state that

> . . . the impact is on decisions in which there is sufficient structure for computer and analytic aids to be of value but where managers' judgment is essential [Keen and Morton, 1978:2].

The essence is that when a manager's decision-making process is not structured, the computerized system cannot be relied on to produce results by itself. Unstructured decisions "require the judgment of the manager to make qualitative tradeoffs and subjective assessments [Keen and Morton, 1980:35]."

DSS development, as previously mentioned, has paralleled rapid technological advancement.

> With the present availability of mini-computers and even micro-computers, desk top machines, time-shared general purpose systems, and data communication networks, managers now have access to powerful systems for relatively little cost [Keen and Morton, 1978:3].

An effective manager/computer relationship could not exist in the era of large mainframe computers. There was no easy access, the input and output of data being accomplished by a third party. Turnaround times were slow, and the resulting formats were often confusing. Most importantly, the subjective nature of the decision process could not be addressed. The microcomputer, however, is fast becoming a familiar instrument. The most

> . . . important advantage of microcomputer-based local networks is that they put computing power right at the fingertips of the people who need it most--the nontechnical end users [Beeler, 1982:58].

Also, since this microcomputer market is growing "at a 40% annual rate, increased competition will spur on technological development and thrust it toward serving the end user [Dillon, 1981:10]."

The essence of decision support is to provide a workable tool for the manager; for success, the design of the system is vital. "Only when focusing on the decision first and then defining the information required to support it, is it possible to see <u>which</u> data are worth collecting [Keen and Morton, 1978:85]." It can be readily seen that

an effective DSS cannot be implemented and forgotten; development is an iterative and continuing process. Initially the manager and DSS builder should agree on a subproblem, designing a system around it. After a period of use, the system should be analyzed, modified if necessary, and expanded to include more of the total problem. Thus positive development occurs in increments, with the manager and builder interacting to produce the desired results.

> This cycle is repeated three to six times over the course of a few months until a relatively stable system is evolved which supports decision making for a cluster of tasks [Sprague, 1980:10].

The manager himself is actually the system designer, with the DSS builder expanding the process according to evolving system requirements.

Software Interface

Another key aspect of a DSS is the software interface. "The system is what it looks like to the user; thus the software interface between the user and the underlying models and data bases must be humanized [Keen and Morton, 1978:99]." It takes a lot of technical expertise to produce effective software that the manager will use, but the result of a thorough design is an increased likelihood of user acceptance. Keen and Morton present three major software issues to be dealt with (1978:182):

1. Communicability: The system must be genuinely conversational, with a well-defined, simple process for submitting requests, switching to new data or routines, and so on.
2. Robustness: The DSS should be "bombproof." It should contain internal checks to prevent users making mistakes or nonsensical output being printed.
3. Ease of Control: The DSS programming personnel should remind themselves daily that "this is the user's system, not mine." It may be useful to create a prototype system, a mockup of the interface, to check that the users feel they can operate the DSS in their way and not feel forced into a sequence or vocabulary unnatural for them.

Data Base Design

Additionally, effective DSS implementation requires a sound Data Base Management System (DBMS). The problem with even large-scale MIS data application systems is that they are essentially collections of individual records or files. To generate desired output, specific input is required. The typical MIS data file system is departmentalized; each application requires specific data elements which supply unique information for separate organizational functions.

A DBMS approach is fundamentally different. A DBMS

> . . . is designed to incorporate all the data elements or data resources that mirror the organization's activities--both automated and nonautomated--to meet the information requirements of the whole enterprise in an accurate, controlled, and timely manner [Van Duyn, 1982:6].

The result is an orientation toward an interdepartmental perspective, emphasizing the interwoven relationships

between the data elements. A DBMS also provides managers with direct access to information, facilitating timely and more accurate decision making.

Perhaps the most important aspect of the DBMS is its evolutionary capability. This is vital to a dynamic organizational environment, since the data elements are subject to rapid changes over time. An effective DBMS would have to provide for rapid data changes while ensuring that the resulting information flow remained congruent. This capability is provided through the separation of programs and data (Sprague and Watson, 1977:147).

Such program elements comprise the Data Dictionary Subsystem (DDS) of a DBMS. Van Duyn lists the functions of the DDS (1982:24-25):

1. Description of unique identifications and physical characteristics of each data element.
2. Information as to the source, location, usage, and destination of each entity, as well as to the creation of a new entity whenever that occurs.
3. Retrieval and cross-referencing capabilities.
4. Accurate picture of the relationships of data to other data, of data to data structures (e.g., data bases and files), of data to processes and processing structures (e.g., systems and programs), of data to processing, and of data to reports.
5. Validation and redundancy checking capabilities.
6. Naming standardization, an essential factor for handling and controlling the data resource.
7. Providing users the most current information about data in the DBMS.
8. Facilities to interact with one or more DBMS.
9. Consistent and timely documentation.
10. Reporting facilities.

In essence, the DDS controls the flow of data elements. It provides an interface between data and the DSS,

converting raw data into information useful to the decision process. However, it should be emphasized that the DDS does not contain permanent organizational data. The data elements themselves evolve in a changing environment and are converted into useful information through the DDS. Together they comprise the DBMS, an essential part of a successful DSS.

From this description it is evident that decision support systems can be tailored to meet the decision-making requirements of many diverse organizations. One promising arena for the use of DSS techniques is the realm of production scheduling.

Computerized Scheduling

Production scheduling has resisted the introduction of computerized, interactive approaches. This is true for a variety of reasons; the significant ones are listed by Godin (1978:335):

1. Scheduling problems are often huge combinatorial situations. In the past, in order to make the problems solvable, assumptions had to be made to reduce their breadth. These assumptions were frequently unrealistic and unacceptable to the operations managers responsible. The cost and time to develop and run scheduling systems which would not require such assumptions was prohibitive.
2. Scheduling problems change so rapidly that the systems are not flexible or sophisticated enough to keep up with them.
3. Operations managers frequently lack any real understanding of computer-based systems. Thus, they display a reluctance to use such systems (interactive or otherwise).

4. The software and hardware to support flexible interaction were not available (at reasonable cost) until the last few years.
5. Schedulers are, in general, buffered from outside pressures; they don't really have a good grasp of the implications of many of their decisions. Hence, motivation to design and use scheduling systems is lacking.

Approaching the production scheduling problem from a DSS perspective offers a promising solution to these problems. Both schedule development and DSS development are iterative, evolutionary processes. The key question to be addressed in Chapter III is: how can DSS methodology be advantageously applied to the Air Force maintenance scheduling process?

Scope and Limitations

This research will provide a basic model of the wing level maintenance scheduling process in the Strategic Air Command. This model will be the basis for establishment of a scheduling Decision Support System designed to enhance the results of maintenance planning. The data for the model building will be assimilated from the 28th Bombardment Wing at Ellsworth AFB, South Dakota; it will consist of statistics related only to the B-52H aircraft stationed there. The research will address maintenance planning, specifically development of the monthly maintenance plan.

Research Question

Can a decision model of the maintenance scheduling process be constructed which will serve as a basis for a Decision Support System which will support development of monthly aircraft maintenance planning?

Objectives

The objectives of this research are:

1. Define the structure of the maintenance scheduling process.

2. Identify decision processes involved in producing a monthly maintenance schedule.

3. To construct a functional model which includes scheduling factors, relationships, and decision policies.

4. To show how the model could provide a means for establishment of a maintenance scheduling DSS.

CHAPTER III

METHODOLOGY

DSS Design Process

This chapter presents the evolution of the Decision Support System (DSS) design process as applied to the Air Force maintenance scheduling problem. It has been shown that the characteristics of a DSS are to:

> . . . (1) assist managers in their decision process in semistructured tasks; (2) support, rather than replace, managerial judgment; [and] (3) improve the effectiveness of decision making rather than its efficiency [Keen and Morton, 1978:1].

It remains to be shown that a DSS can provide these benefits in an aircraft maintenance scheduling environment. Improving effectiveness implies redefining the existing decision process; the more unstable the environment, the greater is the need to focus on increasing managerial effectiveness. This is the central focus of the DSS concept and a compelling reason to consider its relationship to aircraft maintenance scheduling.

Decision Framework

Applying DSS methodology to the aircraft maintenance scheduling process requires an understanding of the framework in which relevant decisions are made. Keen and Morton have developed a taxonomy of organizational

activities which is presented in Figure 3-1 (1978:87). According to Zalud, scheduling is a semistructured activity, consisting of activities which cannot be entirely automated because the decision process involves subjective managerial judgement; he provides examples (included in Figure 3-1) for the three management activity categories relating to the scheduling process (Zalud, 1981:21). A management control activity,

> . . . (1) involves considerable interpersonal interaction; (2) it takes place within the context of the policies and objectives developed in the strategic planning process; and (3) its paramount aim is to assure effective and efficient performance [Keen and Morton, 1978:82].

Constructing a master production schedule would therefore lie within the semistructured management control area of organizational activity. This type of decision process is most effectively supported by a decision support system, providing a balance between managerial judgement and computer automation. "Under these conditions the manager <u>plus</u> the system can provide a more effective solution than either alone [Keen and Morton, 1978:86]."

Besides the basic decision framework, it is necessary to consider the context of the maintenance scheduling activities. As presented in Chapter I, there are several agencies concerned with the scheduling process, all involved within a series of overlapping time frames. It is obvious from observation of the aircraft maintenance

TYPE OF DECISION/ TASK	MANAGEMENT ACTIVITY			SUPPORT NEEDED
	Operational Control	Management Control	Strategic Planning	
Structured				Clerical, EDP or Mgmt Science Models
Semistructured	Expediting	Master Schedule	Plant Size/Location	Decision Support System
Unstructured				Human Intuition

Fig. 3-1. Decision Framework

scheduling process that complex scheduling "problems are not always structured or unstructured in their entirety but only in terms of particular phases within the problem-solving process [Keen and Morton, 1978:95]." For example, scheduling during periods of increased readiness requires an increased reliance on judgemental factors since decisions must be reached under conditions of relative uncertainty, involving more rapid priority changes and increased personnel pressure. Such rapid alterations confirm the desirability of a DSS approach, since the keys to effective scheduling performance are timeliness and flexibility, which a fully automated, structured system cannot provide.

Four important characteristics of management situations in which a DSS can be useful to the managerial decision process are given by Keen and Morton (1978:96-97):

1. The existence of a large data base, so large that the manager has difficulty accessing and making conceptual use of it.

2. The necessity of manipulation or computation in the process of arriving at a solution.

3. The existence of some time pressure, either for the final answer or for the process by which the decision is reached.

4. The necessity of judgement either to recognize or decide what constitutes the problem, or to create alternatives, or to choose a solution. The judgement may

define the nature of the variables that are considered or the values that are put on the known variables.

It has been shown that aircraft maintenance scheduling possesses all four characteristics, making it an ideal candidate for a decision support system.

DSS Design Strategy

The overall DSS design strategy is illustrated in Figure 3-2 (Keen and Morton, 1978:175). The starting point on the continuum is the descriptive model of the existing decision process. At the opposite end are the normative models; they are

> . . . proposals for change: they define the potential range of designs for an information system. For a nonstructured decision, there is no one best solution but rather a range of potential designs [Keen and Morton, 1978:174-175].

The distance implied between these extremes is relative; the larger it is, the greater are the possible returns in terms of increased managerial decision effectiveness, but also the greater are the risks involved in implementation. It should be emphasized here that implementation of the normative decision process cannot be achieved immediately; this is why the DSS design range is shown for an area between the extremes. A DSS implies an iterative implementation process;

> . . . what is needed is a design that begins from a position close enough to the descriptive model for implementation to be practicable and to permit further evolution [Keen and Morton, 1978:176].

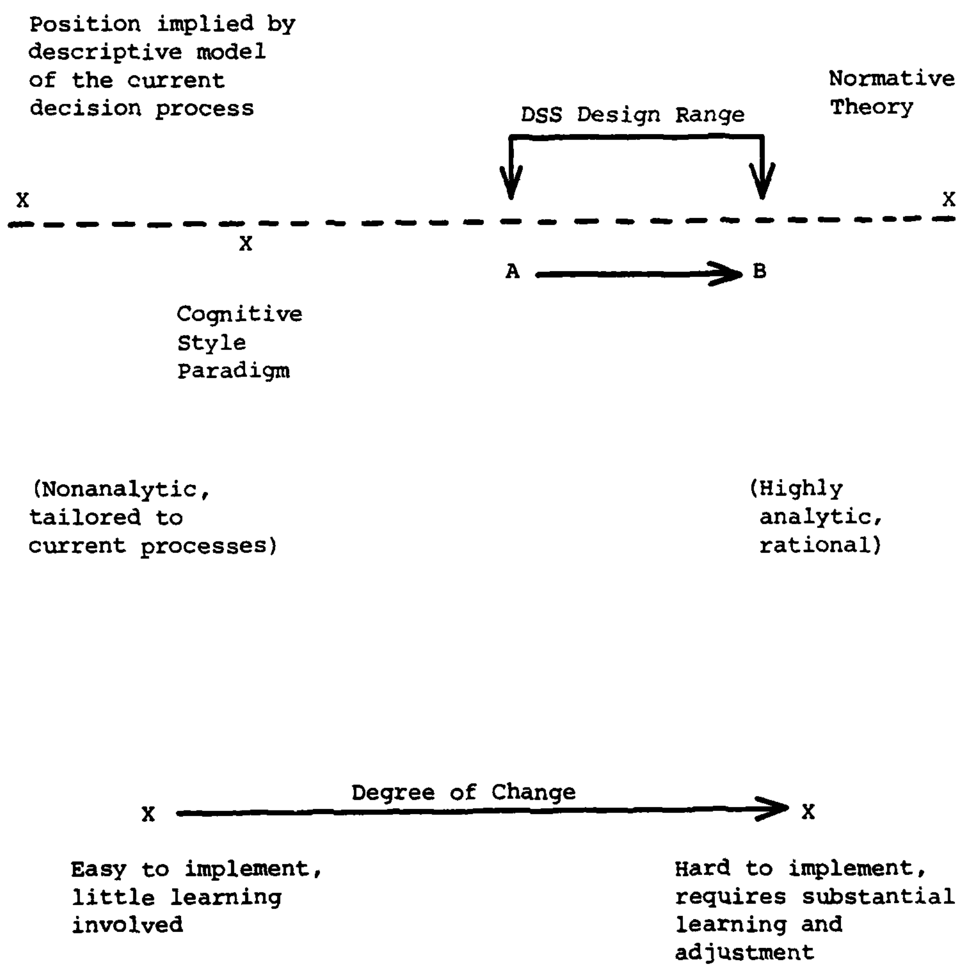


Fig. 3-2. DSS Design Strategy

Preceding the initial DSS implementation (point A in Figure 3-2) is a point labeled as the cognitive style paradigm. This refers to the personality and decision-making style of a manager or group of managers. Germane to this concept is that the DSS designer must be aware of the user's view of what is important in the decision process under study.

> The cognitive style paradigm emphasizes the problem-solving process rather than cognitive structure and capacity. It categorizes individual habits and strategies at a fairly broad level and essentially views problem-solving behavior as a personality variable [Keen and Morton, 1978:74].

The implication of this design strategy is that the normative model (what ought to happen) does not exist and could not be implemented immediately. Instead, in comparing the descriptive and normative models, a range of choices exists concerning design alternatives. Additionally, care must be taken to determine the cognitive style of the system's users to assure that the DSS will increase decision-making effectiveness by making it compatible with the information needs of the managers actually involved in its use. The DSS design range implies that evolution from initial implementation (at point A) to a point further down the continuum (at B) is possible before a complete reevaluation of the continuum is required. At this time the decision system can be analyzed to determine if introduction of the DSS has changed the normative model.

The descriptive model would then lie somewhere between points A and B, and system evolution could still continue.

DSS Design for Maintenance Scheduling

A DSS for scheduling should consist of

> . . . three components (an optimization model, an interative scheduling capability, and a data base); the system is designed to enable the scheduling manager to develop objective and implementable schedules [Balachandrian and Andris, 1981:812].

An overall DSS design concept for the maintenance scheduling problem is illustrated in Figure 3-3. It consists of four interrelated areas, with provisions for expansion and evolution. The design process should begin with the delineation of a wing-specific function scheduling model. This involves defining the relationships and interactions among the agencies described in Chapter I, and will be dealt with in detail in Chapter IV. Once a suitable model has been constructed and validated, data required to support an interactive, computerized DSS can be assembled as required by the decision logic.

The data base development should stress user involvement from its inception. This is an essential concept from the cognitive style paradigm presented in the previous section; only the user can be really aware of the data necessary for transformation into the information required to aid the scheduling decision process. It should also be stressed that data base design is an

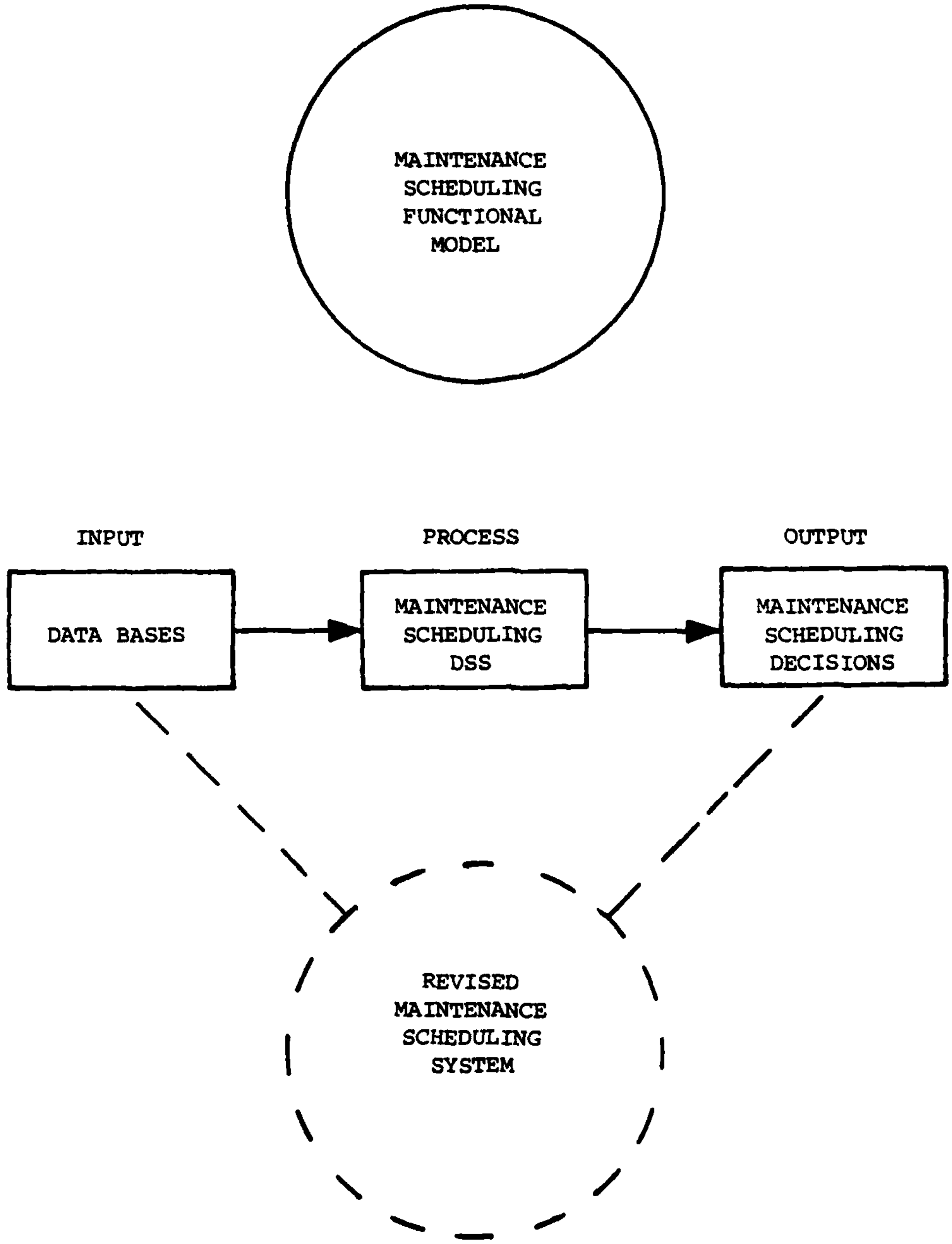


Fig. 3-3. Maintenance Scheduling DSS Design Concept

iterative process; as the system develops, additional information will be found to be necessary, while some previously incorporated data could be determined to be redundant or superfluous.

The functional model and the data base provide a basis for development of the computerized system, designed to produce usable information for the maintenance scheduler; this information supports the scheduling decision-making process. The automated system includes computer hardware, a data base management system such as that described in Chapter II, and the software interface between the DSS and the manager/scheduler. "The system, as seen by users, is the interface. They are very sensitive to the quality of the interface [Keen and Morton, 1978:182]."

System output consists of maintenance scheduling decisions. These are made by the scheduler with the decision support provided by the automated DSS. These should be more effective, due to the interaction between the scheduler and the computer, than the decisions which were being made without the DSS.

After initial implementation, the DSS designer and the user continue to interact to determine how the system should evolve. Since it is difficult to anticipate user needs in advance, the initial system serves as a proving ground, providing the user with hands-on experience

and provoking fresh insights. From this experience the user rapidly becomes adept at providing the impetus for system evolution through suggested additions and improvements.

> This means that the first stage in the long-term process of evolution should be . . . to design and deliver a system that is seen as usable and useful now; but the interface software should be flexible enough to allow rapid extension and addition of routines. The second phase, which would probably begin after three months to one year of experience with the original system, will involve design of a few powerful new routines that extend the decision maker's efforts and abilities [Keen and Morton, 1978: 185].

Eventually this feedfc ward concept will lead to a reevaluation of the design continuum, a new descriptive model and perhaps a revised normative model. Thus the system output becomes the input for a new stage, requiring a revised functional model, data base, and processing network. This evolution is represented by the revised system area in Figure 3-3.

The Descriptive Functional Model

The initial step in DSS design/implementation is the description of the decision activity. Knowledge of the activity's operation is contained in what Pease calls its process model.

> The process model for any activity, whether top-level or subordinate, identifies the information required in a plan for that activity, the means for obtaining that information, and the applicable constraints [Pease, 1978:729].

In particular, a process model contains the following information:

1. Tasks that compose the process.

2. Sequential constraints among the tasks which create a partial ordering among them.

3. Either the identities of the planners for the various tasks, or their durations, unless the task is to be wholly specified by the user.

4. Resources required.

5. Constraints that relate resource assignments to tasks.

6. Identities of the schedulers responsible for the required resources.

7. Data required for each task and assignment (Pease, 1978:729).

In the maintenance scheduling context, Pease's process model becomes the descriptive functional model, and should not be confused with the maintenance scheduling DSS process identified in Figure 3-3. However, it still contains the information he listed. It should be emphasized that, although production scheduling is a dynamic, ever-changing process, this initial descriptive model is necessarily static. Although the overall maintenance scheduling process has evolved and has been defined by regulation, each wing exhibits certain idiosyncracies in implementation. A basic functional model, providing

useful relationships, would serve as the basis for specific DSS characteristics which would guide system implementation. "Thus, the model becomes the link between the real phenomenon and the manager's system [Schoderbek et al., 1980:282]."

Maintenance Scheduling Model Architecture

In order to construct a functional maintenance scheduling model, it is necessary to determine the structure to use in its development. A promising technology has been developed for the U.S. Air Force by Sof Tech Corporation based on a Structural Analysis and Design Technique. This program is called Integrated Computer-Aided Manufacturing (ICAM). ICAM

> . . . is directed toward increasing manufacturing productivity through the systematic application of computer technology. The ICAM Program approach is to develop structured methods for applying computer technology to manufacturing and to use those methods to better understand how best to improve manufacturing productivity [ICAM, 1981:3].

Specifically, the maintenance scheduling model incorporates the structure explained in the ICAM Definition ($IDEF_0$) Function Modeling Manual.

> $IDEF_0$ is used to produce a function model which is a structured representation of the functions of a manufacturing system or environment, and of the information and objects which interrelate those functions [ICAM, 1981:3].

This modeling technique provides an architecture for systems design; it can be visualized as a blueprint which

offers a graphic definition of "the fundamental relationships--the functional interfaces, identification of common, shared and discrete information, and dynamic interaction of resources [ICAM, 1981:3-4]." This section includes a definition of terms and concepts essential to an understanding of the application of the $IDEF_0$ methodology to the maintenance scheduling model to be presented in Chapter IV.

<u>$IDEF_0$ Diagrams</u>

The systems model is composed of a set of diagrams which graphically depict its component parts and underlying functional relationships. On each diagram, each major component of that structural level is shown as a box.

> Each detailed diagram is the <u>decomposition</u> of a box on a more general diagram. At each step, the general diagram is said to be the "parent" of the detailed diagram. A detailed diagram is best thought of as fitting "inside" a parent box [see Figure 3-4] [ICAM, 1981:19-20].

Each box signifies an active functional process occurring over time to provide a transformation from input to output. Boxes are connected by arrows representing data which is transformed. The arrows can be interpreted as providing definition for the boxes; they do not provide a flow between functions or a sequence of functions (ICAM, 1981:22).

The arrows affect the boxes in various ways. Each arrow's characteristic can be determined by noting the side of the box where it enters or leaves (see Figure 3-5).

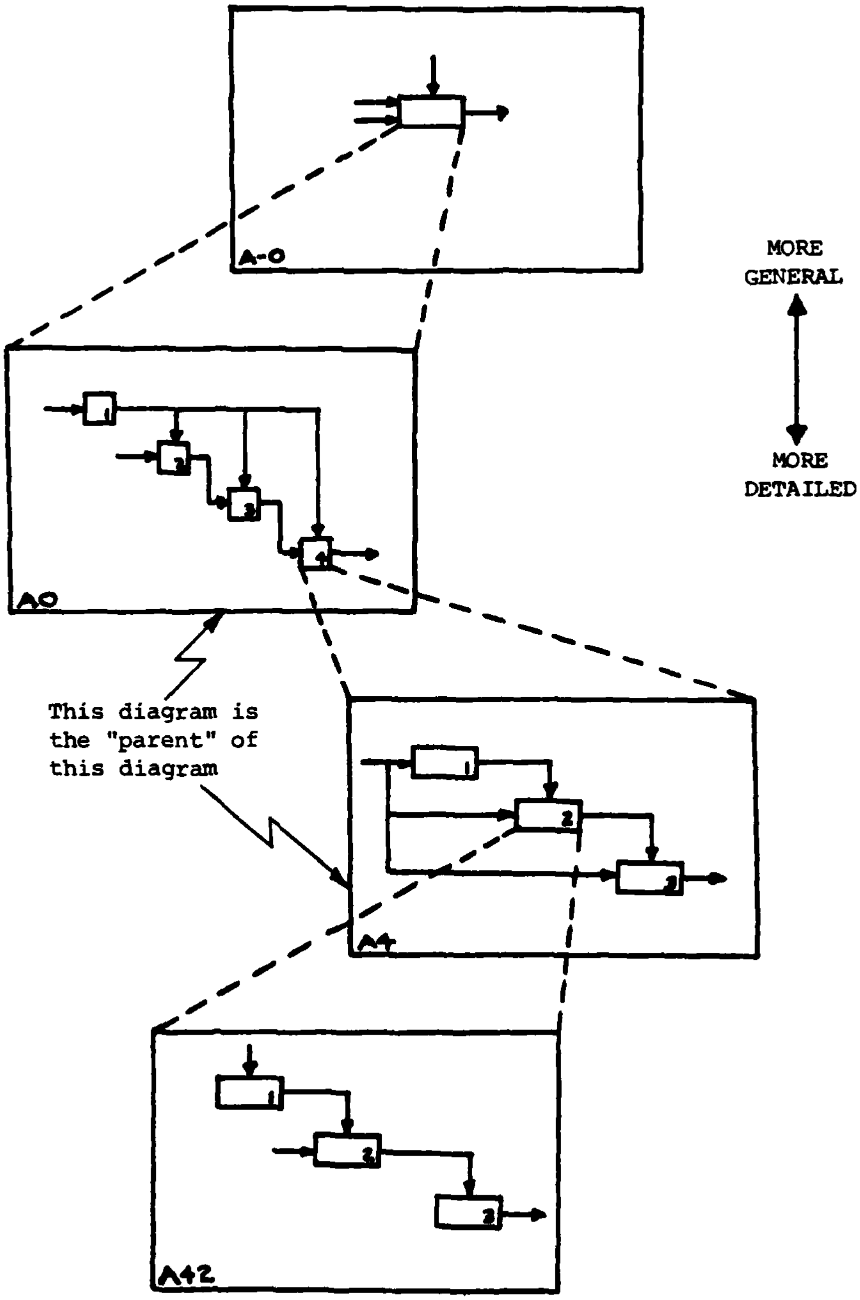


Fig. 3-4. Decomposition of Diagrams
[ICAM, 1981:20]

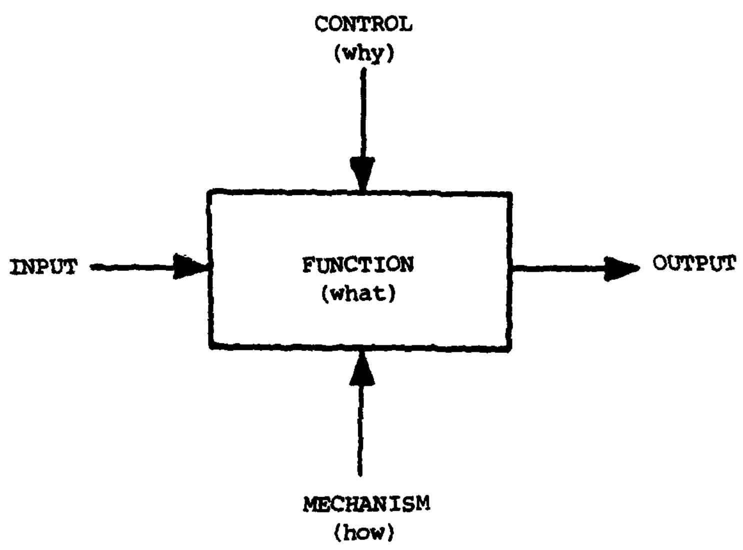


Fig. 3-5. Box/Arrow Relationship
[ICAM, 1981:23]

An input arrow signifies that data which is transformed by the function represented by the box. An output represents data which either results from or is created by the functional box. A control is different than an input: it determines the function or tells why the transformation is taking place. Finally, a mechanism defines the source which enables the function's performance (i.e., a person, machine, tool, or similar device). The mechanism shows how the function is performed. It is important to note that a function cannot be performed until all required data, as shown by incoming arrows, has been provided. Each arrow is labeled to identify what it represents; if it branches, each branch is also labeled.

> On any given diagram, data may be represented by an internal arrow (both ends connected to boxes shown on the diagram) or a boundary arrow (one end unconnected, implying production by or use by a function outside the scope of the diagram)[ICAM, 1981:26].

The source or destination of such boundary arrows is found by referring to the parent diagram.

Diagram Notation

Diagrams are arranged in a hierarchical format. A box on a particular diagram may be broken down into a more detailed structure by creating subsequent diagrams. Such a hierarchy is depicted in Figure 3-6 (ICAM, 1981:33). This type of structure is known as a node tree.

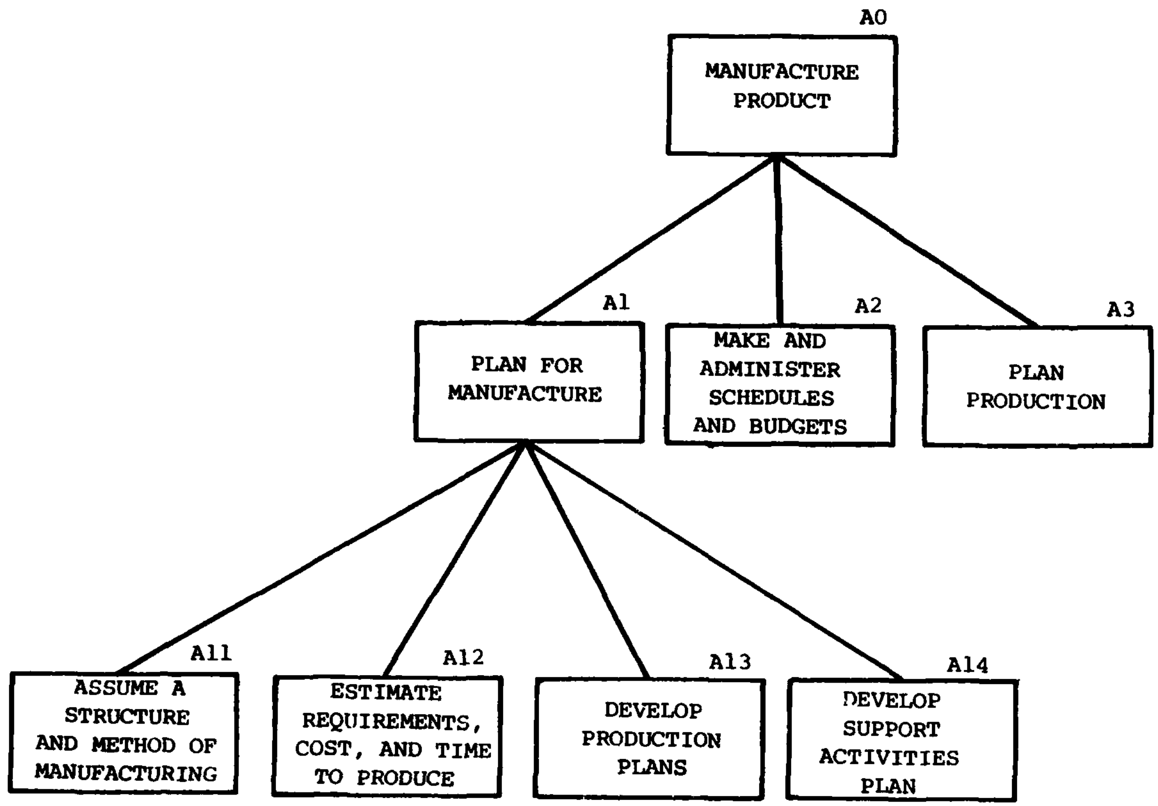


Fig. 3-6. Example of a Hierarchy [ICAM, 1981:33]

All node numbers of $IDEF_0$ diagrams begin with the letter A, which identifies them as "Activity" or function diagrams. A one-box diagram is provided as the "context" or parent of the whole model. By convention, this diagram has the node number "A-0" (A minus zero) [ICAM, 1981:33].

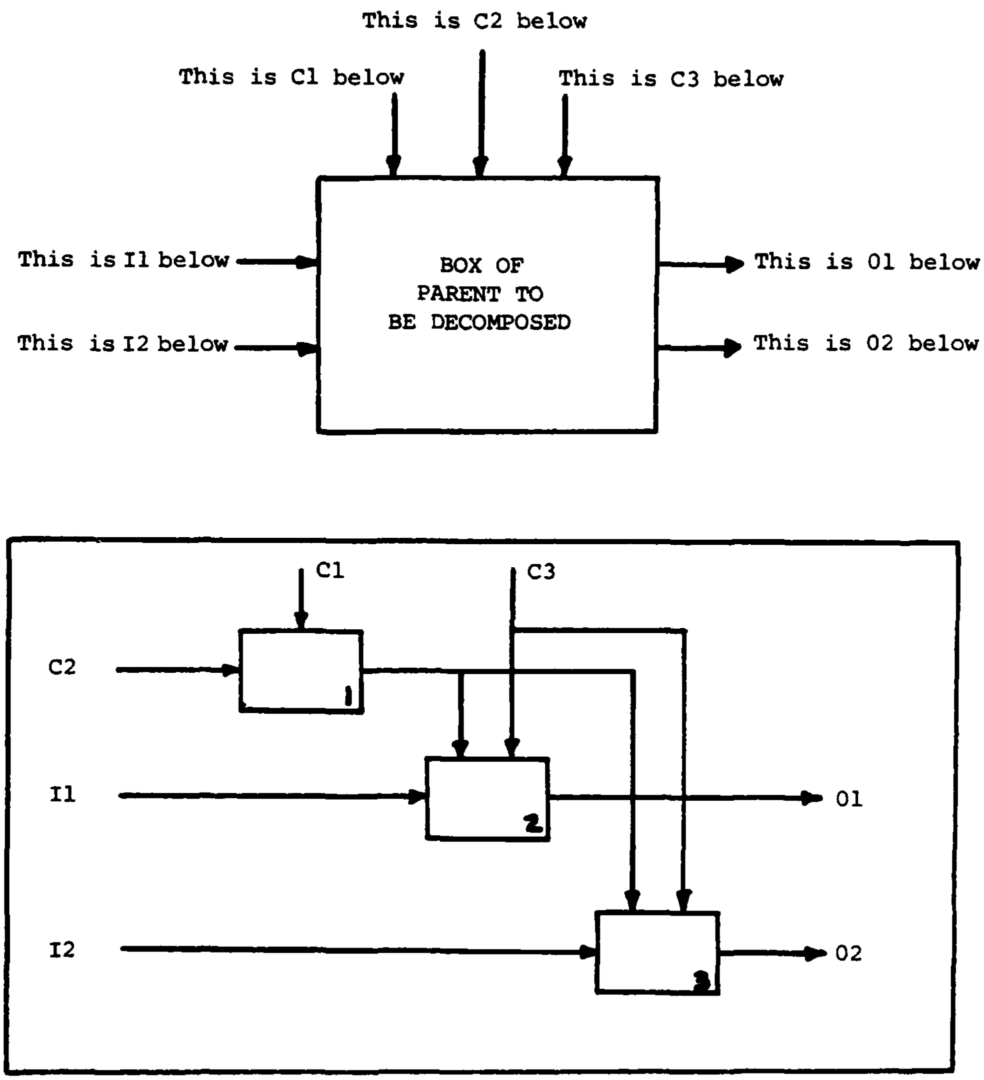
The arrows associated with the A-0 diagram are called external arrows because they represent the system environment, while the box establishes the context of the system being modeled.

For all other diagrams, boundary arrows must be specified by an ICOM code.

The letter I, C, O, or M is written near the unconnected end of each boundary arrow on the detail diagram. This identifies that the arrow is shown as an Input, Control, Output, or Mechanism on the parent box. This letter is followed by a number giving the position at which the arrow is shown entering or leaving the parent box, numbering left to right and top to bottom [ICAM, 1981:37].

An example is given in Figure 3-7. An arrow shown as a control or input on the parent diagram does not have to fill a similar role on the decomposition (ICAM, 1981:37).

In addition to diagrams, the $IDEF_0$ methodology provides for written text to aid in system definition. The text is intended to emphasize significance or clarify intent, not to duplicate diagram detail. In addition, a node index is provided for convenience in accessing desired levels of detail.



ICOM codes are written on the decomposed diagram as they appear on the parent diagram.

Fig. 3-7. ICOM Codes
[ICAM, 1981:38]

Modeling Concepts

This chapter has presented an argument for the application of DSS concepts to the wing aircraft maintenance scheduling problem. It has also defined the $IDEF_0$ methodology which will be used to define the functional structure of the maintenance scheduling model. Chapter IV develops this model in detail, through a graphic exposition of its overall context and component parts. Another part of the overall context, the operations scheduling model, was developed by a parallel AFIT master's thesis effort (Moore and Whitmore, 1982).

CHAPTER IV

MAINTENANCE SCHEDULING MODEL

This chapter presents a functional model of the aircraft maintenance scheduling decision process. It incorporates procedures from the ICAM Definition ($IDEF_0$) Function Modeling Manual (ICAM, 1981) explained in Chapter III. The $IDEF_0$ concepts provide the exposition methodology for model development, beginning at the most general decision context and flowing into more specific components of the detailed decision process. This treatment provides a structured representation of the maintenance scheduling decision process, by function. How each of those functions interrelates is also shown through the use of inputs, outputs, controls, and mechanisms.

An index to the functions and subfunctions is illustrated as a "node tree" and can be referred to in the appendix.

Maintenance Activities

The parent module (Figure 4-1) is a coordinated function which transforms unit mission objectives and raw data (inputs) into an aircrew training schedule and a maintenance schedule (outputs). This research specifically concerns the subfunction--planning maintenance

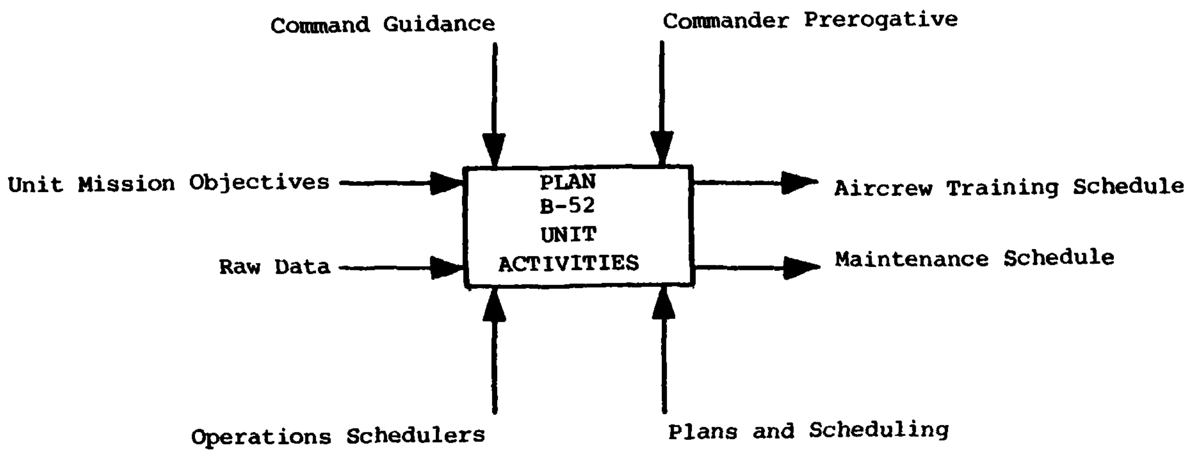


Fig. 4-1. Parent Module (A-0)

activities (Figure 4-2). Another AFIT master's thesis (Moore and Whitmore, 1982) addresses planning aircrew activities.

The decision process of planning maintenance activities (Figure 4-3) involves preparing to plan maintenance and following the operational planning cycle, which was explained in Chapter I. Maintenance management policy is governed by regulations and maintenance operating instructions. Preparing to plan maintenance (Figure 4-4) involves a review of these publications, which provides maintenance schedulers with policy knowledge to determine specific maintenance objectives. An important guideline for scheduling maintenance resources is to achieve a constant utilization rate.

> If the aircraft are evenly distributed over the inspection cycle and are properly scheduled for flying, the workload for a large part of the maintenance complex will be stable and smooth [USAFR 66-1, Vol.1, 1980:A3-9].

The maintenance objectives demand that various data be collected and organized. The resulting information becomes an input, which is integrated throughout the operational planning cycle.

Monthly Scheduling

Adhering to the operational planning cycle to produce a maintenance schedule is accomplished by: planning quarterly, scheduling monthly, refining weekly, and

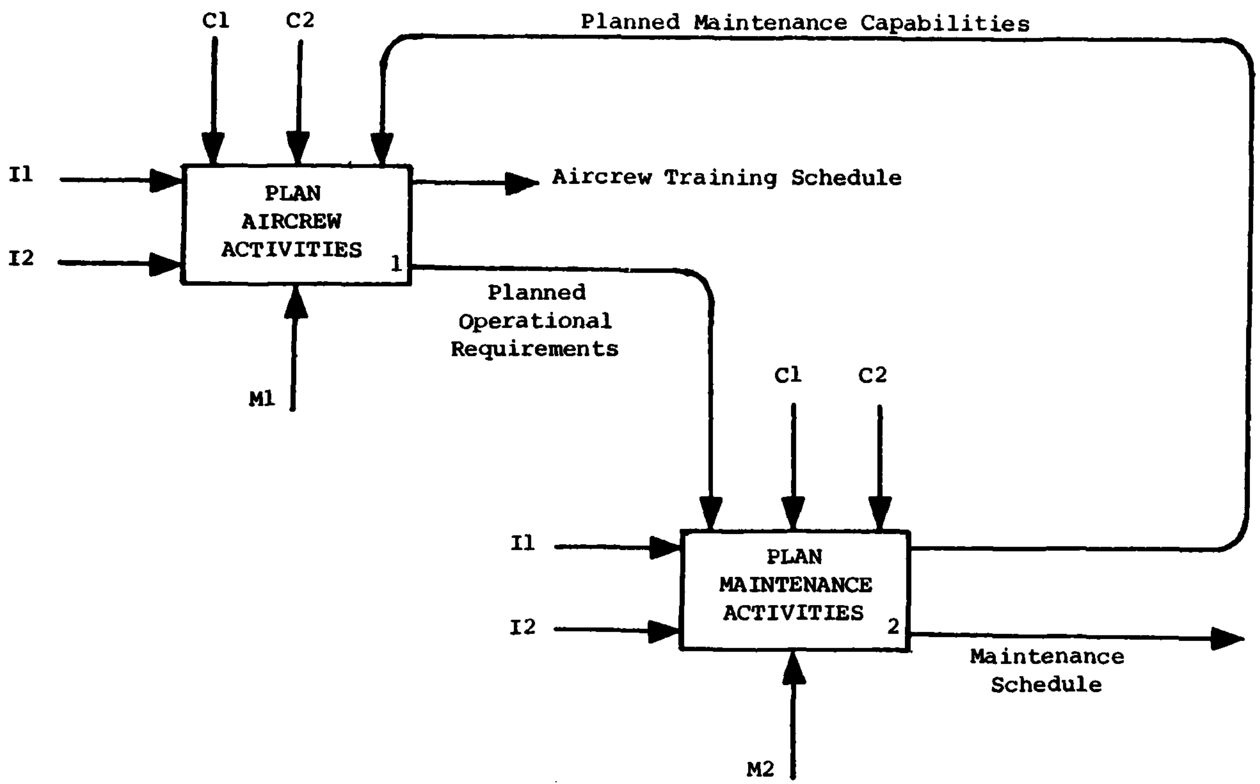


Fig. 4-2. Plan B-52 Unit Activities (A0)

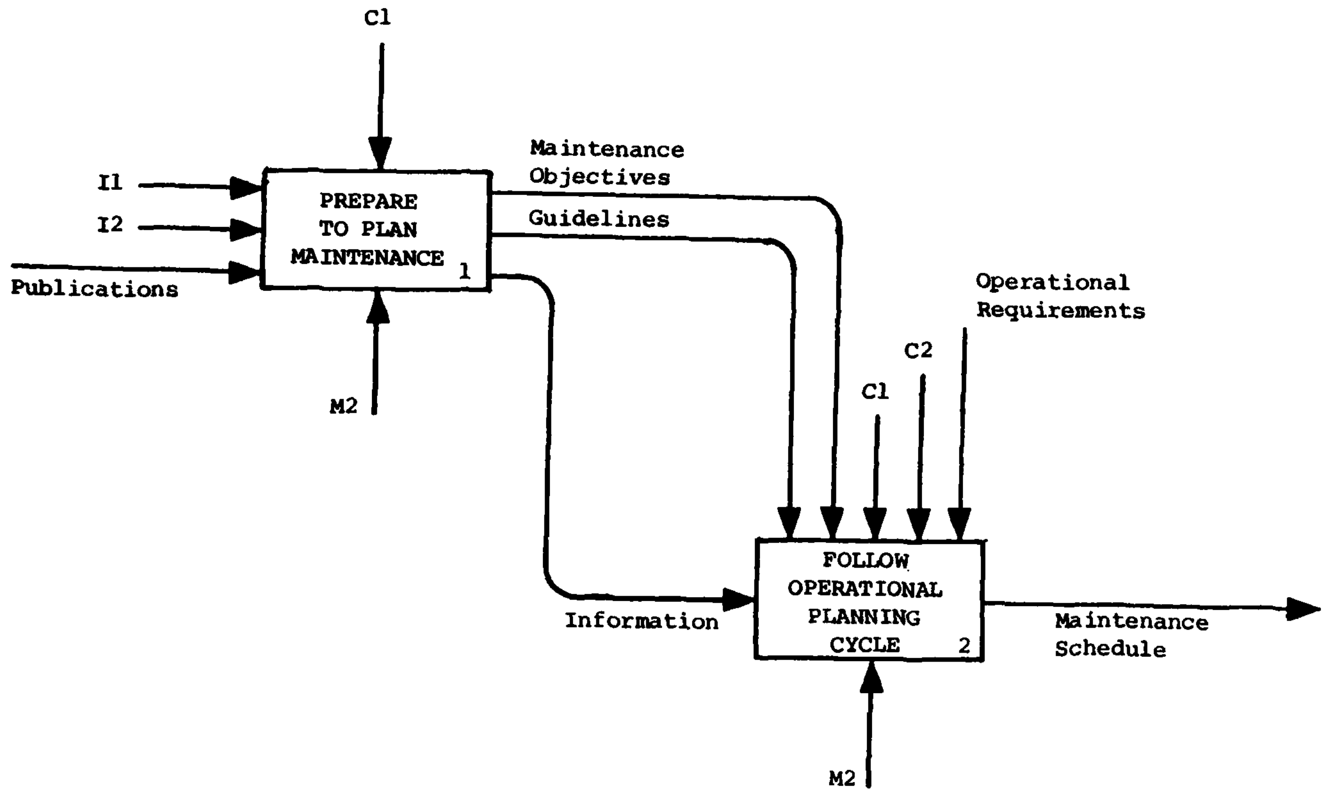


Fig. 4-3. Plan Maintenance Activities (A2)

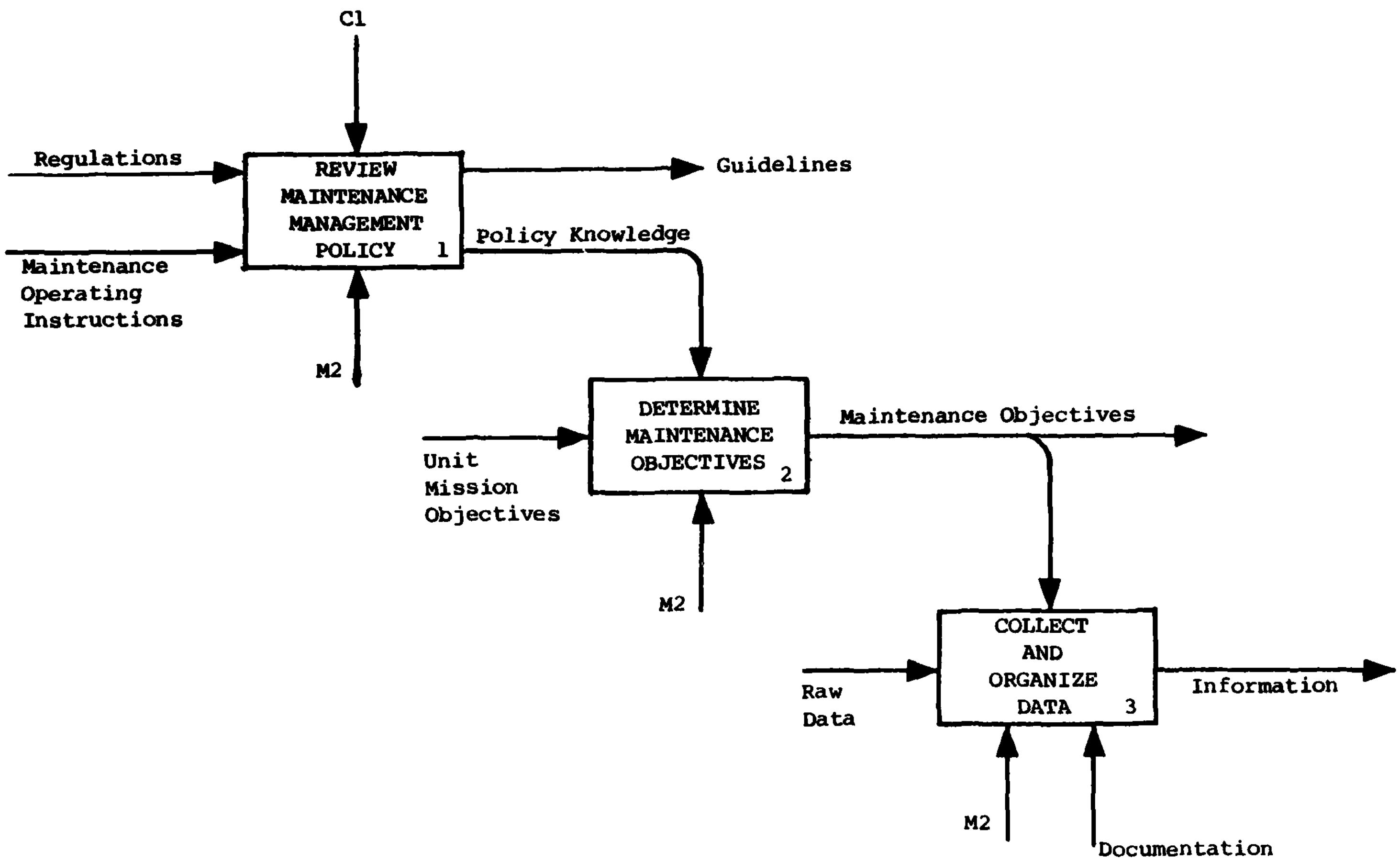


Fig. 4-4. Prepare to Plan Maintenance (A21)

expediting daily (Figure 4-5). The monthly schedule is based on the wing's operational requirements and maintenance capabilities. Information from certain maintenance factors must be input to produce a monthly schedule. Scheduling monthly (Figure 4-6) requires: reviewing operational requirements, computing maintenance capabilities, developing a conceptual maintenance plan, negotiating sorties with operations, and adding an attrition factor. The negotiated contract figure plus the attrition factor are fed back to developing a maintenance plan as inputs. The plan, when published, then becomes the monthly maintenance schedule.

Conceptual Maintenance Plan

Developing a conceptual maintenance plan (Figure 4-7) involves planning aircraft maintenance requirements and planning other maintenance requirements. Both aircraft and other maintenance requirements are controlled by operational requirements, and the maintenance capabilities and objectives; the resulting output is an aircraft utilization schedule.

Planning aircraft maintenance requirements (Figure 4-8) concerns allocating known aircraft requirements and identifying aircraft available for flying sorties. Usually the aircraft left available for flying are not enough to satisfy operational requirements. Thus,

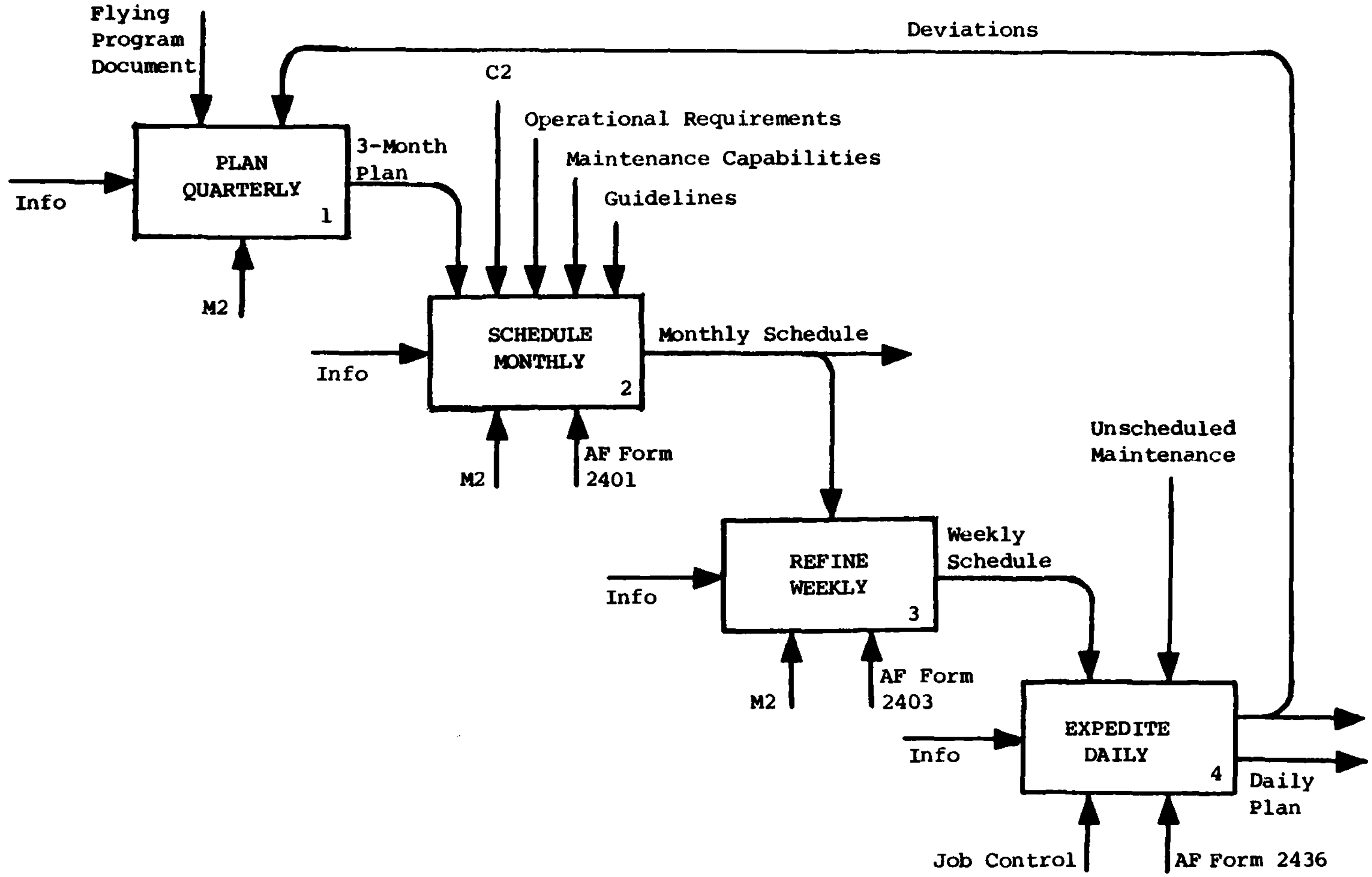


Fig. 4-5. Follow Operational Planning Cycle (A22)

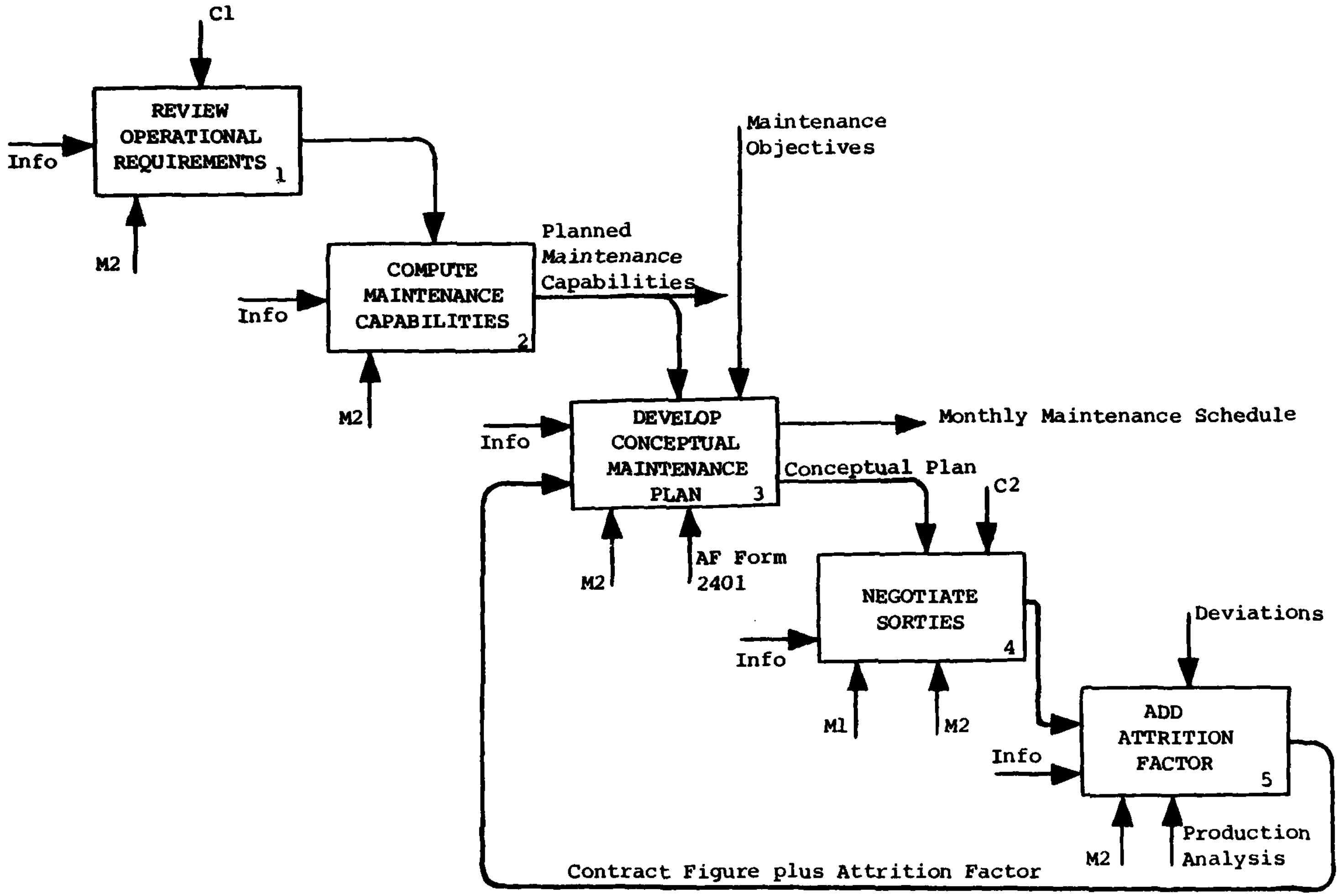


Fig. 4-6. *Schedule Monthly (A222)*

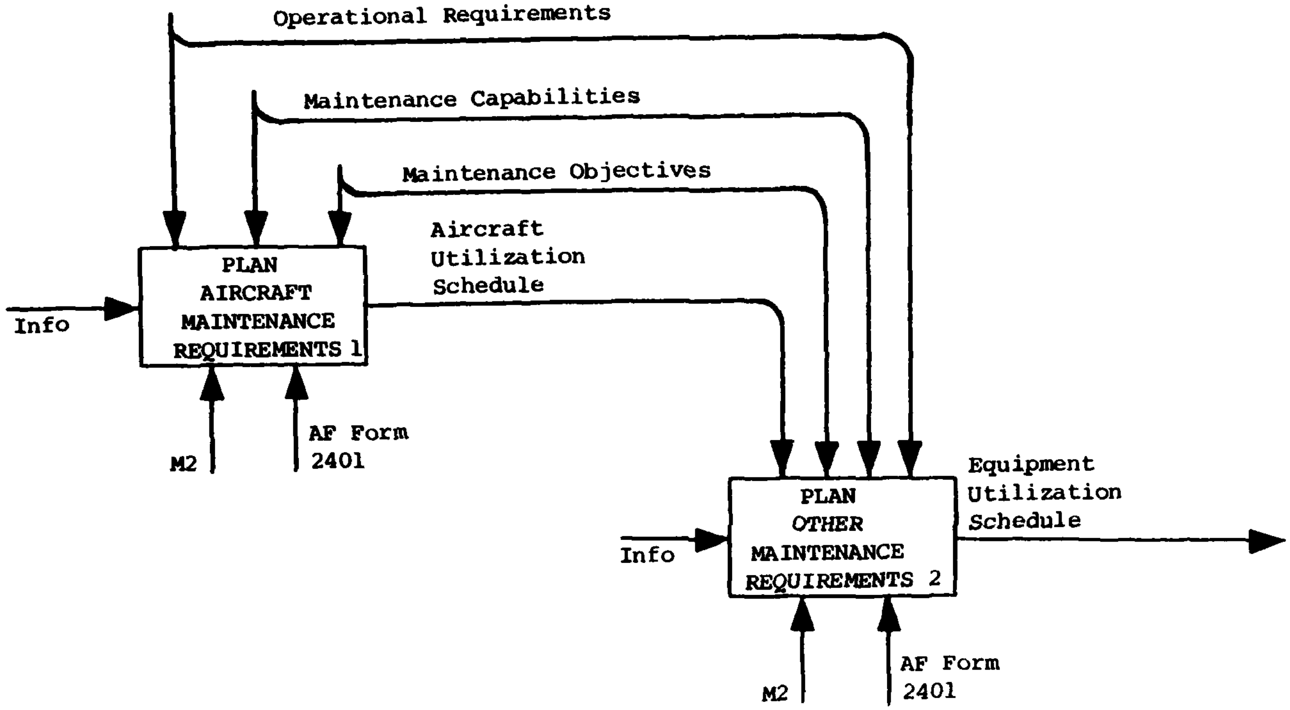


Fig. 4-7. Develop Conceptual Maintenance Plan (A2223)

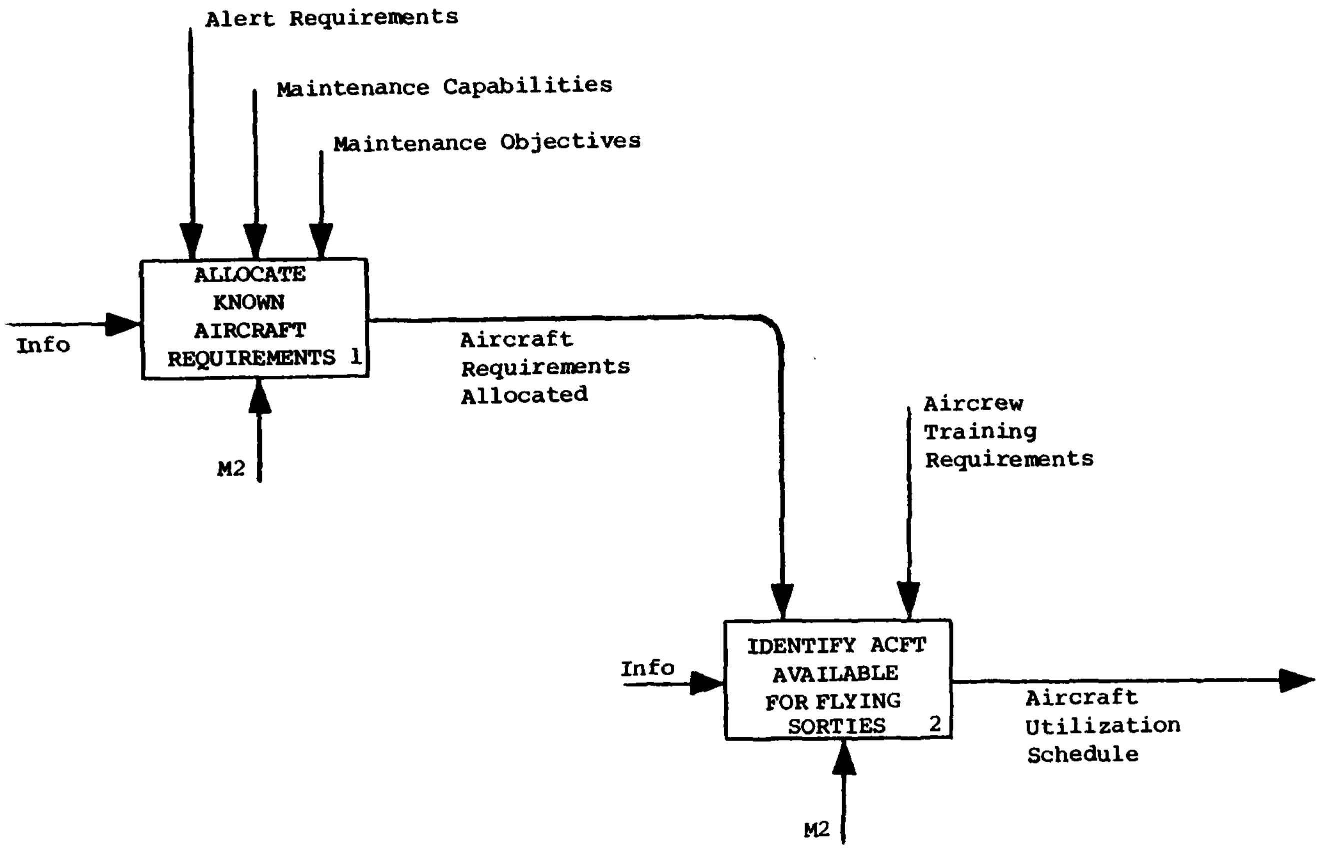


Fig. 4-8. Plan Aircraft Maintenance Requirements (A22231)

operations and maintenance must negotiate the number of sorties. As the number of sorties increases, it becomes harder to meet the maintenance objectives. Planning other maintenance requirements (Figure 4-9) concerns scheduling activities that do not directly involve the aircraft and includes powered aerospace ground equipment (AGE) inspections, maintenance personnel training requirements, Quality Control (QC) activity inspections, and aircrew training devices.

Allocation

It has been previously explained that the conceptual monthly maintenance plan first involves allocating known aircraft requirements (Figure 4-10). These requirements are generally referred to as scheduled maintenance (e.g., alert, PDM, etc.). The scheduler usually allocates resources against known scheduled maintenance requirements in their order of importance.

Alert

The decision process of scheduling aircraft for alert (Figure 4-11) is accomplished by: eliminating the aircraft already on alert from consideration, isolating aircraft not due maintenance, analyzing the resulting aircraft available for alert, and assigning an optimal aircraft from feasible candidates.

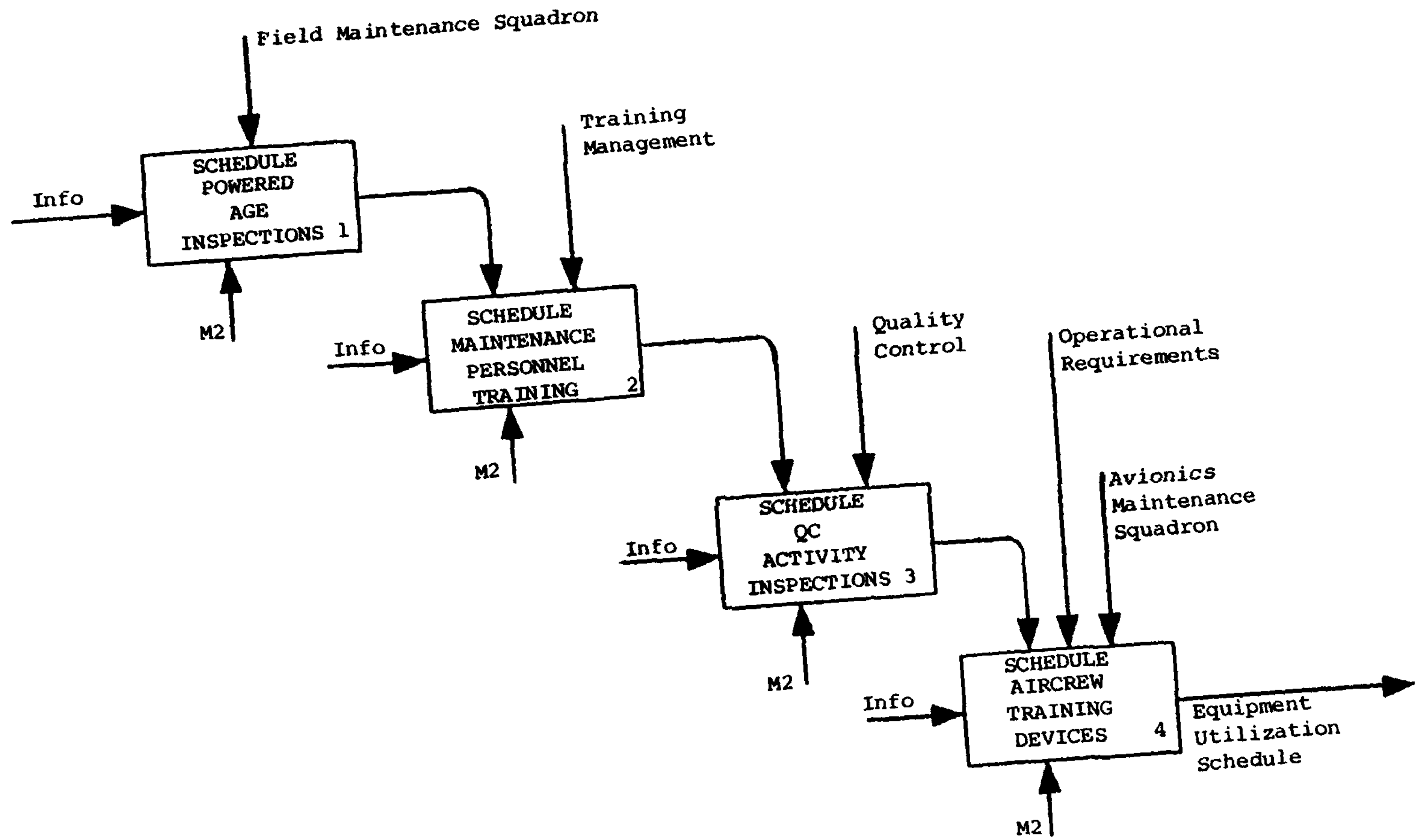


Fig. 4-9. Plan Other Maintenance Requirements (A22232)

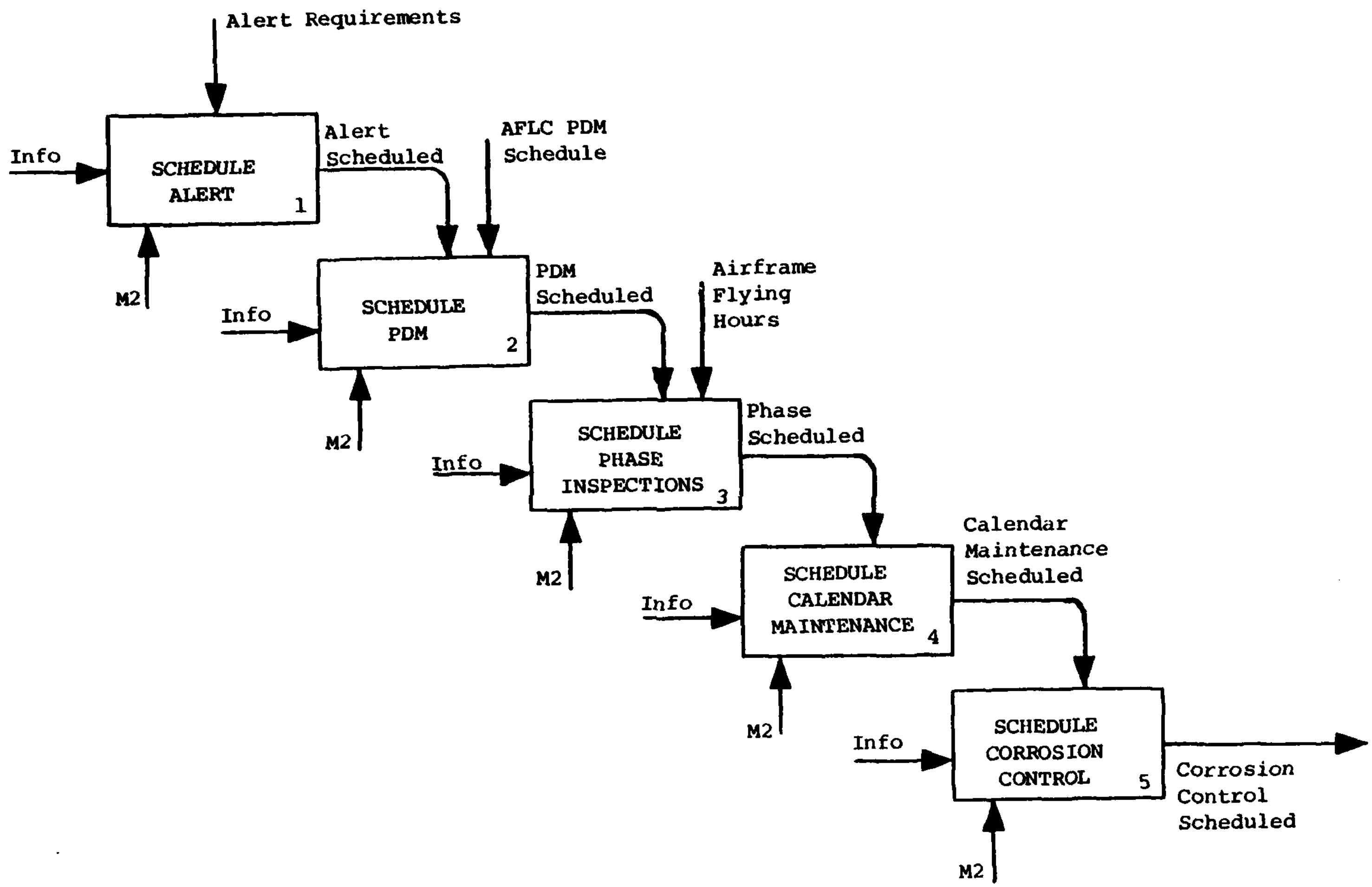


Fig. 4-10. Allocate Known Aircraft Requirements (A222311)

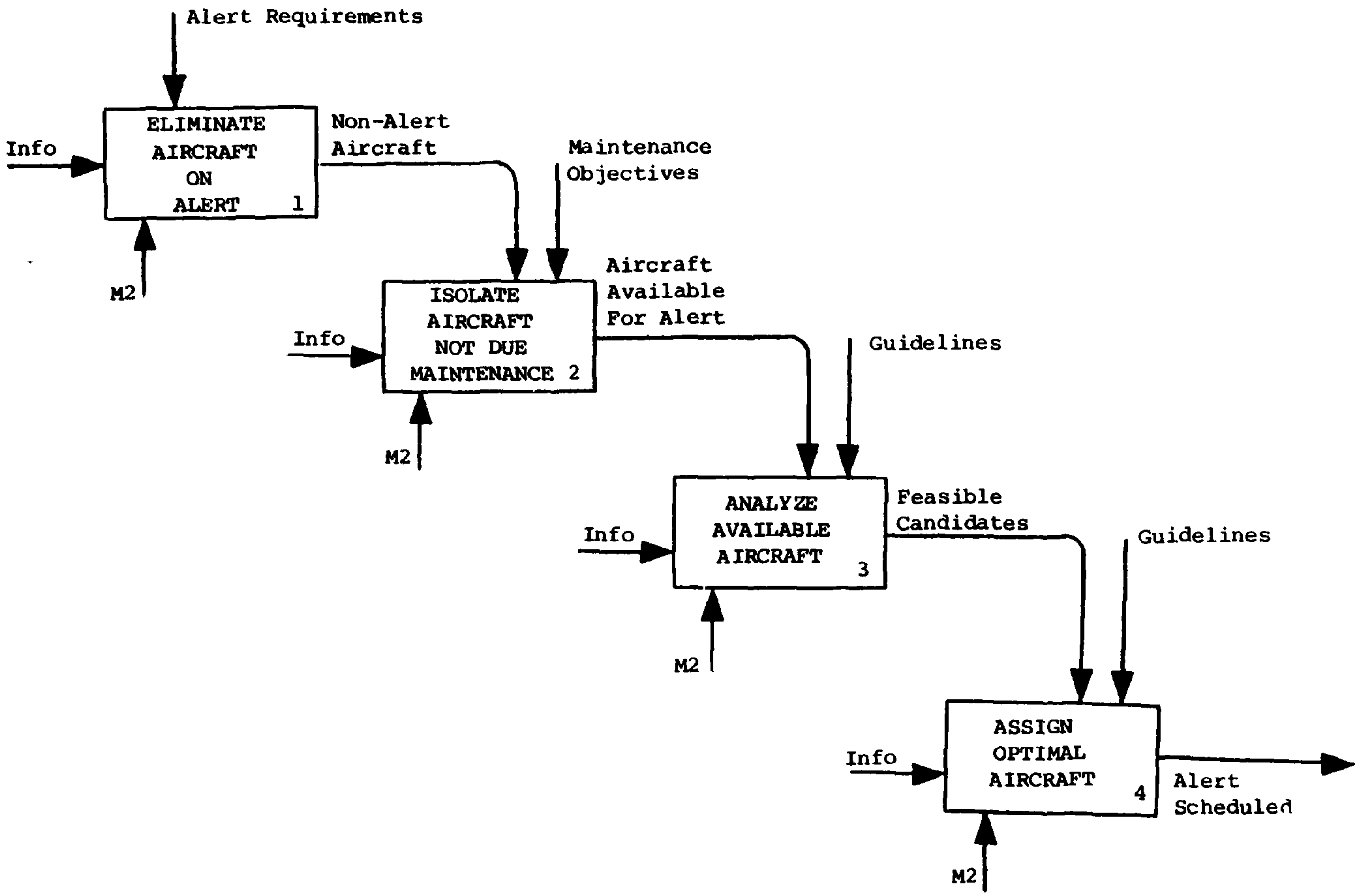


Fig. 4-11. Schedule Alert (A2223111)

Analyzing available aircraft (Figure 4-12) is controlled by the aircraft that are available for alert and guidelines. A specific guideline concerning B-52 aircraft is to cycle the fleet through periods of alert duty (e.g., ninety-day alerts). The management intent is to enhance aircraft maintainability by keeping relatively the same amount of flying time on each airframe. From the available aircraft, the scheduler ranks aircraft by the most airframe flying time. The airframe flying time is an information input from raw data that was collected and organized earlier. Then each aircraft's mission systems, engine status, aircraft systems, and secondary avionics systems (e.g., autopilot, camera, etc.) are ranked. Each of these is ranked using information inputs from the "prepare to plan" stage.

Ranking the aircraft mission systems (Figure 4-13) involves arraying: short range attack missile (SRAM) scores, bombing scores, terrain avoidance (TA) capability, defensive fire control (DFC) capability, and electronic counter measures (ECM) capability. A guideline used in ranking mission systems is the desire to have the aircraft perform well on its first sortie ground alert (FSAGA). The FSAGA is evaluated for quality and reliability. Points accumulated from both of these measures directly impact the wing's overall effectiveness rating. Therefore,

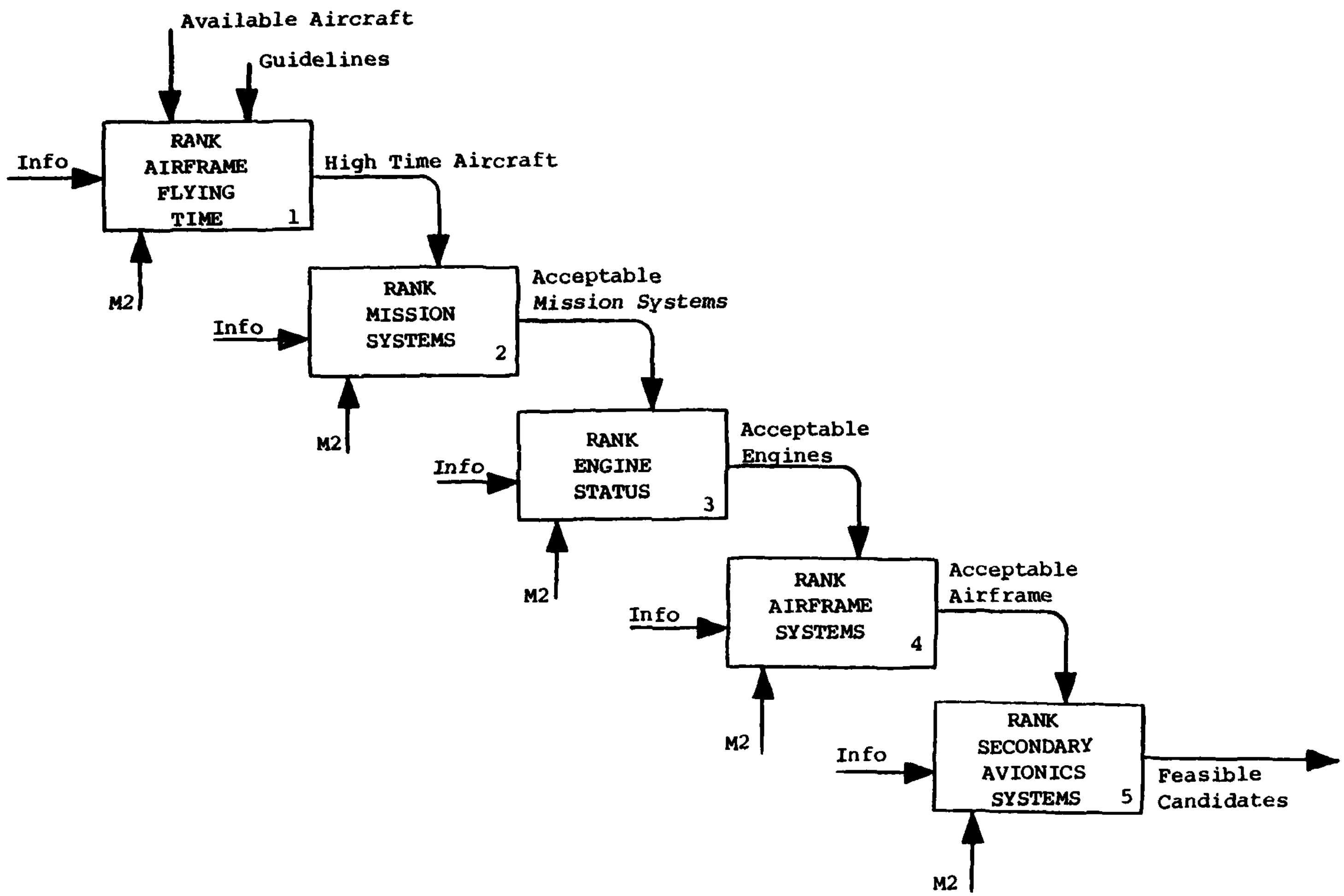


Fig. 4-12. Analyze Available Aircraft (A22231113)

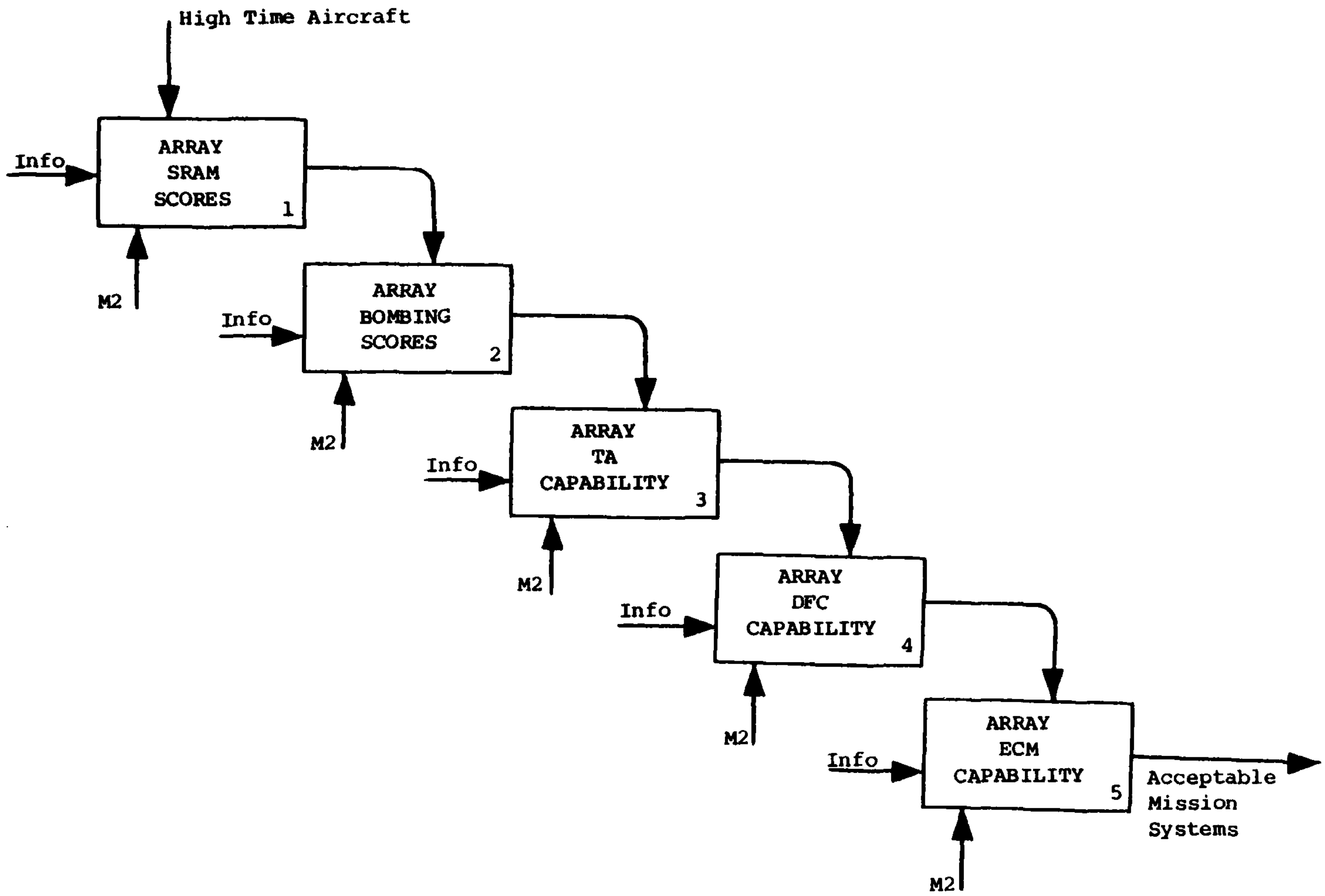


Fig. 4-13. Rank Mission Systems (A222311132)

the maintenance scheduler searches for a well maintained aircraft to place on alert.

If an available aircraft has acceptable mission systems, engines, and airframe/avionics systems, that aircraft becomes a feasible candidate. The scheduler integrates information in assigning the optimal aircraft (Figure 4-14) to fill an alert line. All of the feasible candidates are compared against each other. This comparison leads to a tradeoff between trying to follow the guidelines previously mentioned, and the individual wing's particular requirements for either maintenance or operations. It should be emphasized here that the scheduler's judgement plays an important role in the decision process, since other information inputs (that vary with each wing) have an impact on the decision. Therefore, the resulting compromise controls the selection of the appropriate B-52 for alert. The scheduler continues this iterative process until all alert requirements are scheduled.

PDM

The decision process of scheduling PDM (Figure 4-15) is accomplished by: reviewing the Air Force Logistics Command (AFLC) PDM schedule, displaying aircraft due PDM, coordinating other aircraft maintenance, and scheduling the AFLC planned B-52. The AFLC PDM schedule normally

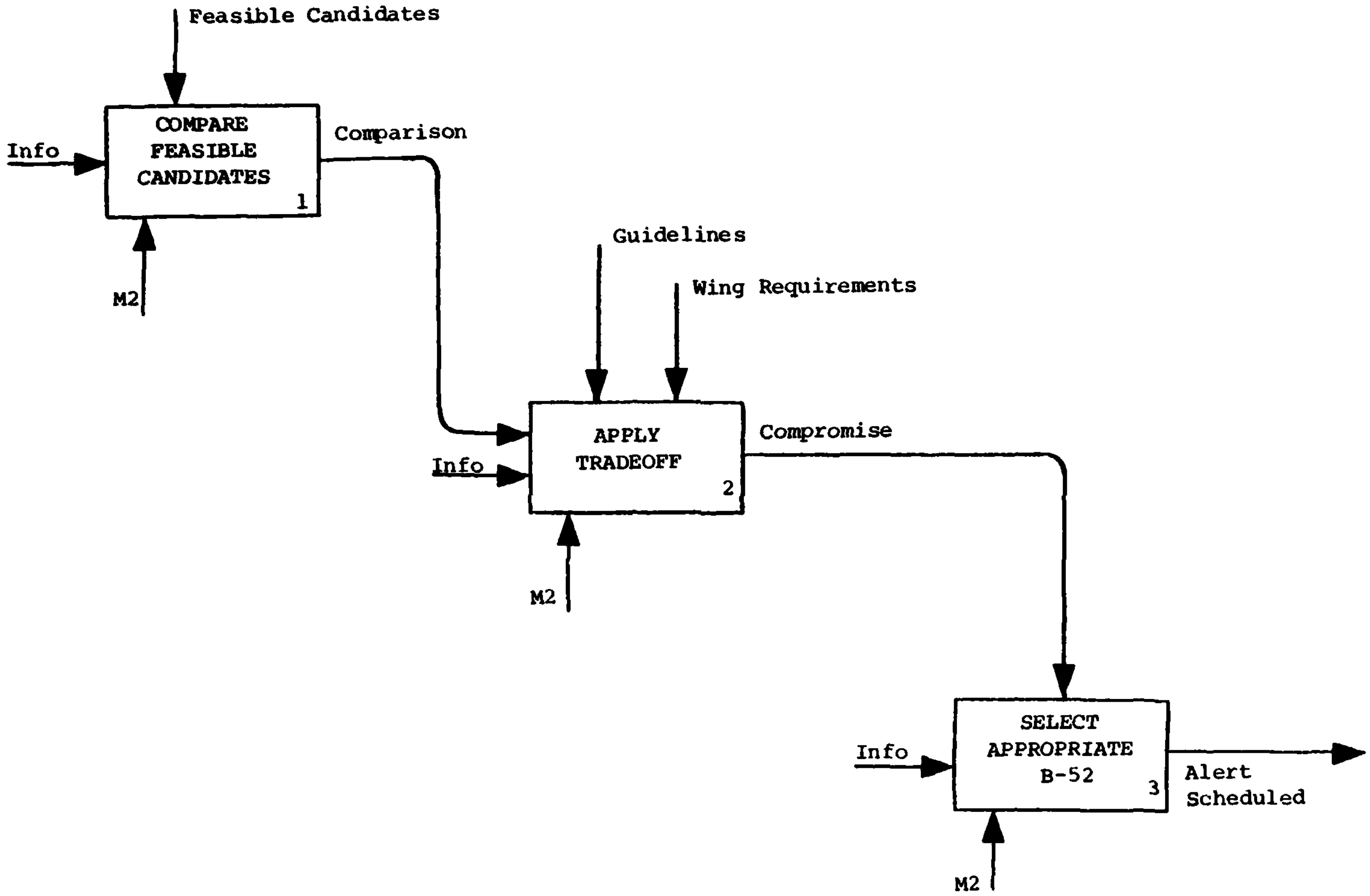


Fig. 4-14. Assign Optimal Aircraft (A22231114)

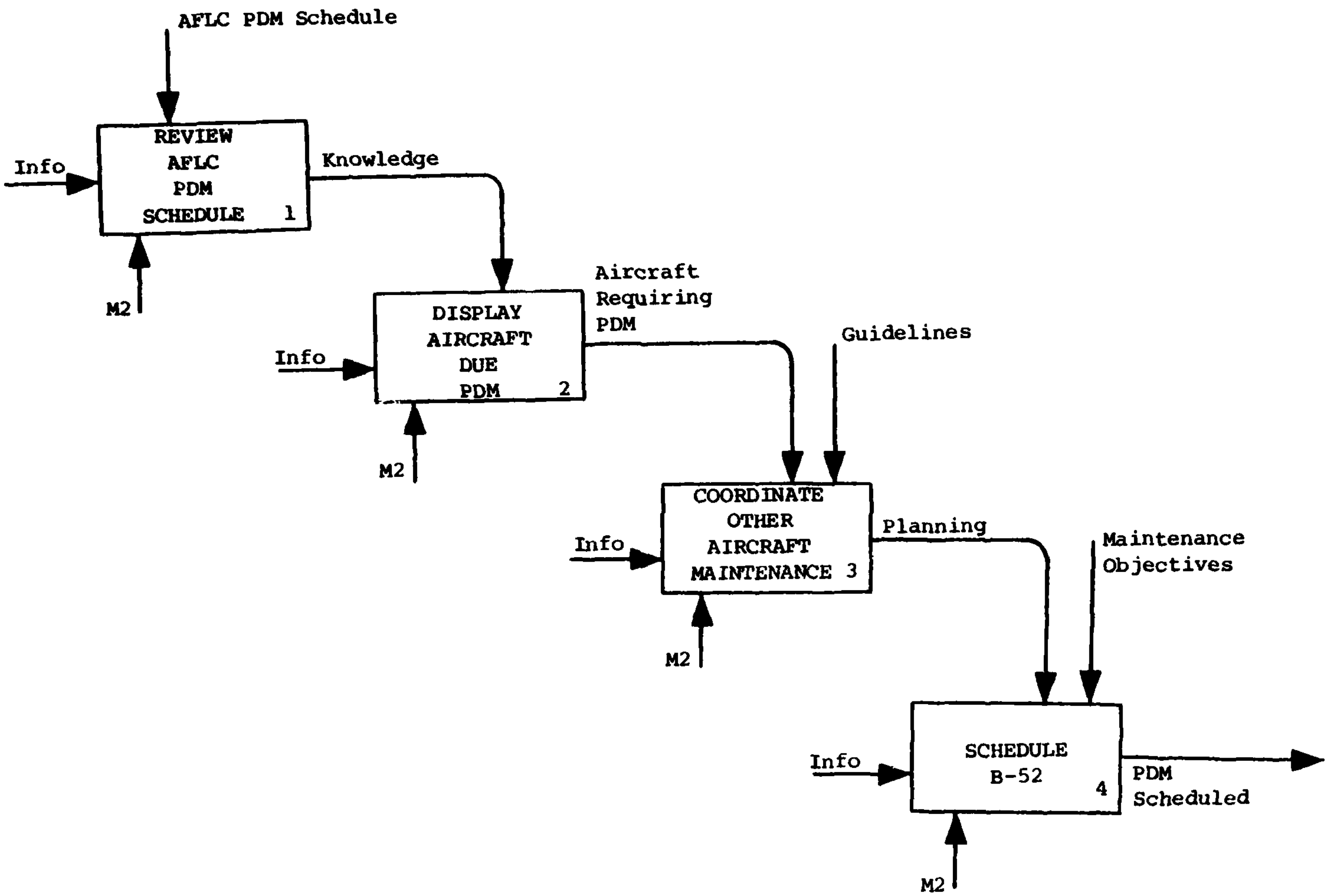


Fig. 4-15. Schedule PDM (A2223112)

specifies, by tail number, when aircraft are due PDM. It is the responsibility of SAC to "assure delivery of equipment [B-52 aircraft] to depot level maintenance facilities as programmed and scheduled [USAFR 66-7, 1973:6]." Therefore, the maintenance scheduler must coordinate other aircraft maintenance requirements for that particular B-52 tail number to preclude the disruption of the AFLC schedule.

<u>Phase</u>

The decision process of scheduling phase inspections (Figure 4-16) is done by first displaying aircraft according to time remaining until phase is due. If time remaining is not sufficient enough to perform another flight, aircraft are identified as requiring a phase inspection. Additionally, aircraft requiring a phase are eliminated from consideration for alert and flying duty. However, the scheduler's judgement or commander's prerogative could override this guideline to meet either alert or flying duty. Normally the phase inspection is not compromised, since it can be accomplished in approximately four days. This includes removing panels, a look-phase, a fix-phase, replacing panels, and running and trimming the engines. From available aircraft, the scheduler assigns the optimal aircraft for phase. When assigning the optimal aircraft (Figure 4-17) for a phase

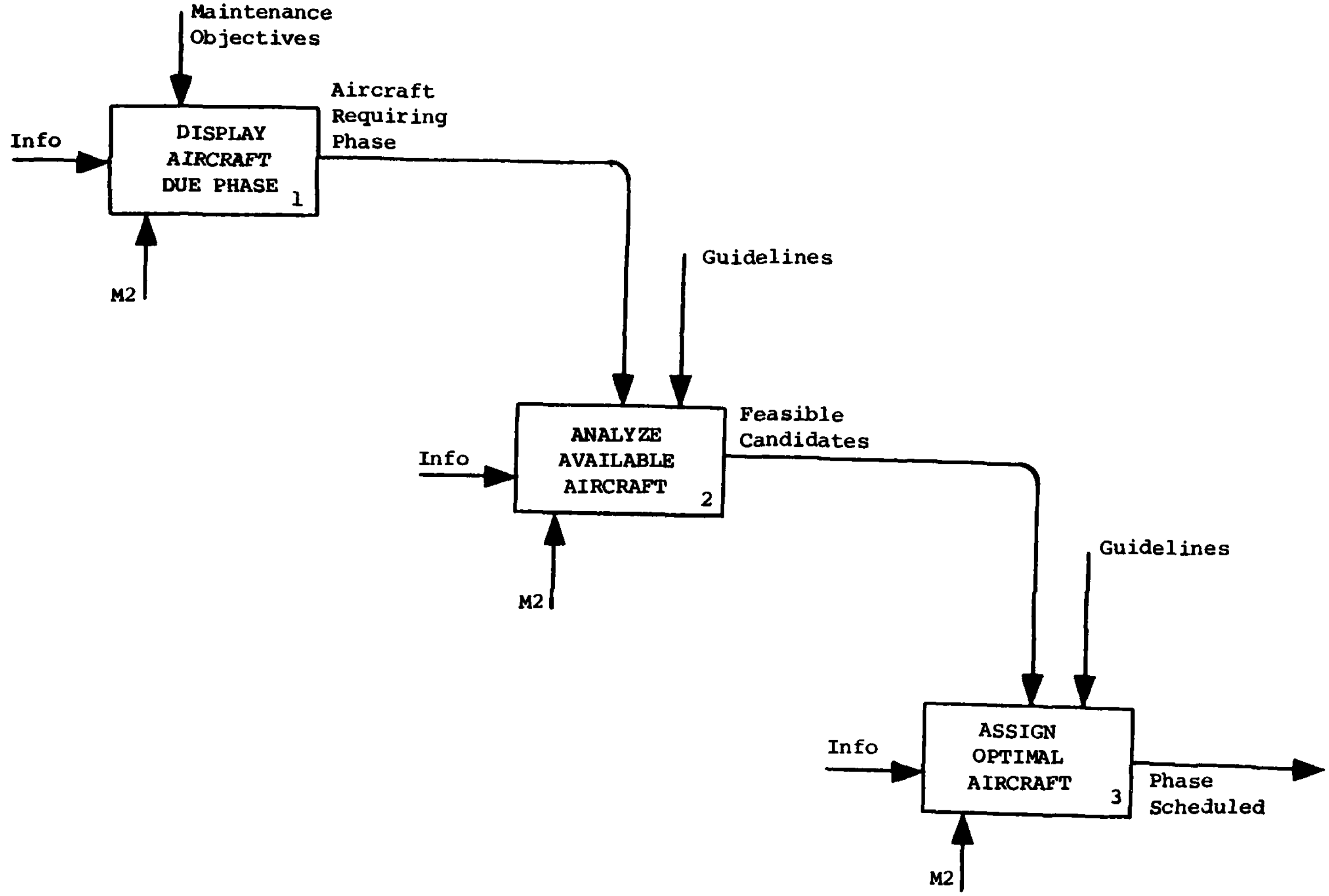


Fig. 4-16. Schedule Phase Inspections (A2223113)

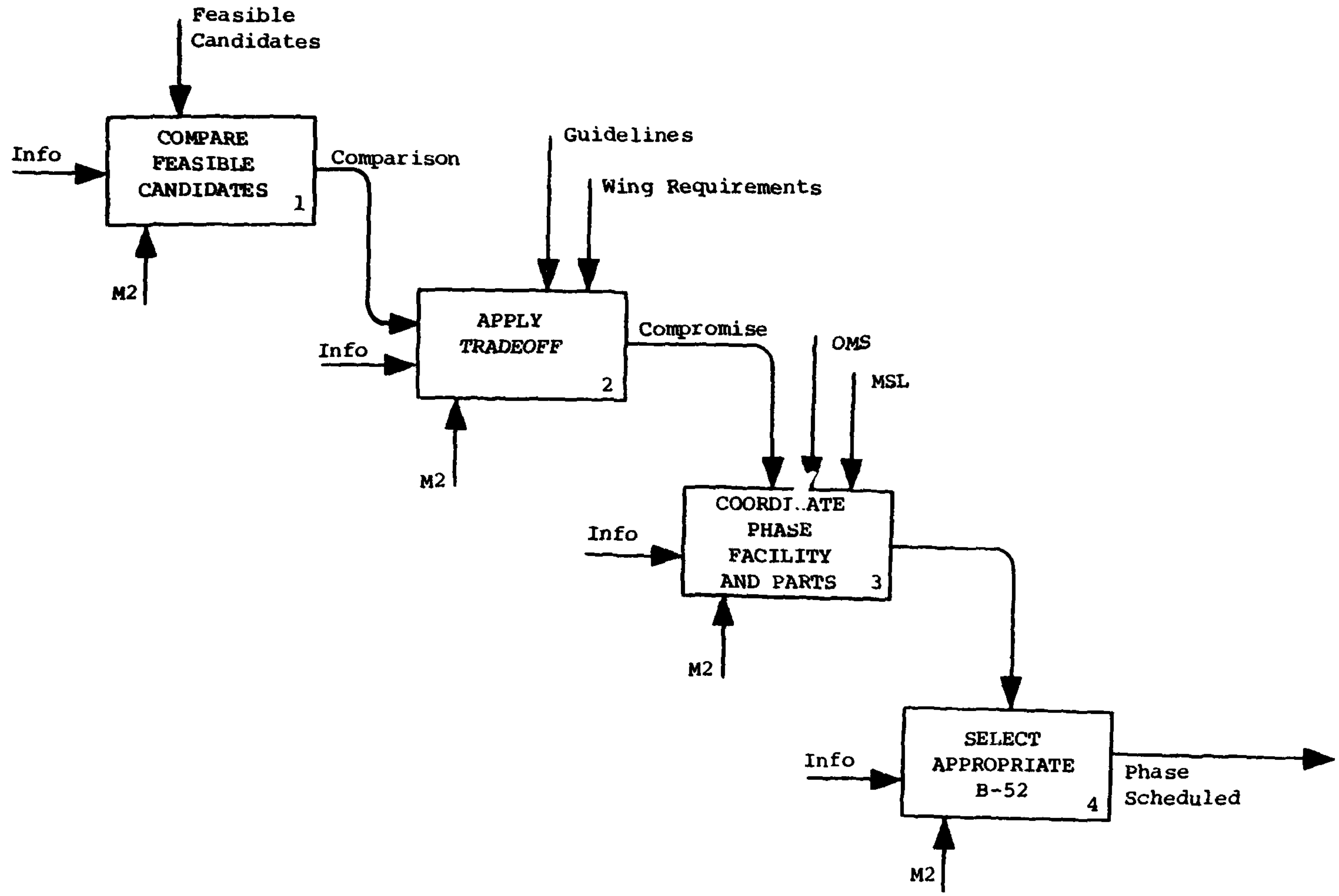


Fig. 4-17. Assign Optimal Aircraft (A22231133)

inspection, the scheduler integrates information inputs to: compare feasible candidates, apply any tradeoffs, coordinate the phase dock with the Organizational Maintenance Squadron (OMS), and arrange for the necessary parts with Maintenance Supply Liaison (MSL) for the specific tail number. When the resources are confirmed, the scheduler selects the appropriate B-52 for a phase inspection.

Calendar Maintenance

The decision process of scheduling calendar maintenance (Figure 4-18) is controlled by scheduled phases and a documentation review. The Documentation work center conducts this review upon receipt of notification by Plans and Scheduling that an aircraft has been scheduled for a phase inspection. The review covers all known TCTOs, Time Change Items, special inspections, and any other calendar maintenance (e.g., engine changes) due against the scheduled phase aircraft. Plans and Scheduling then incorporates an inspection/work package that consolidates all maintenance requirements and governs the calendar maintenance plan. An Inspection/TCTO Planning Checksheet (AF Form 2410) is used to prepare the calendar maintenance plan and conduct the pre-inspection meeting. After coordinating the plan with representatives from Quality Control, MSL, OMS, and any maintenance specialists, the calendar maintenance is considered to be scheduled upon inclusion in the Aircraft Utilization Schedule.

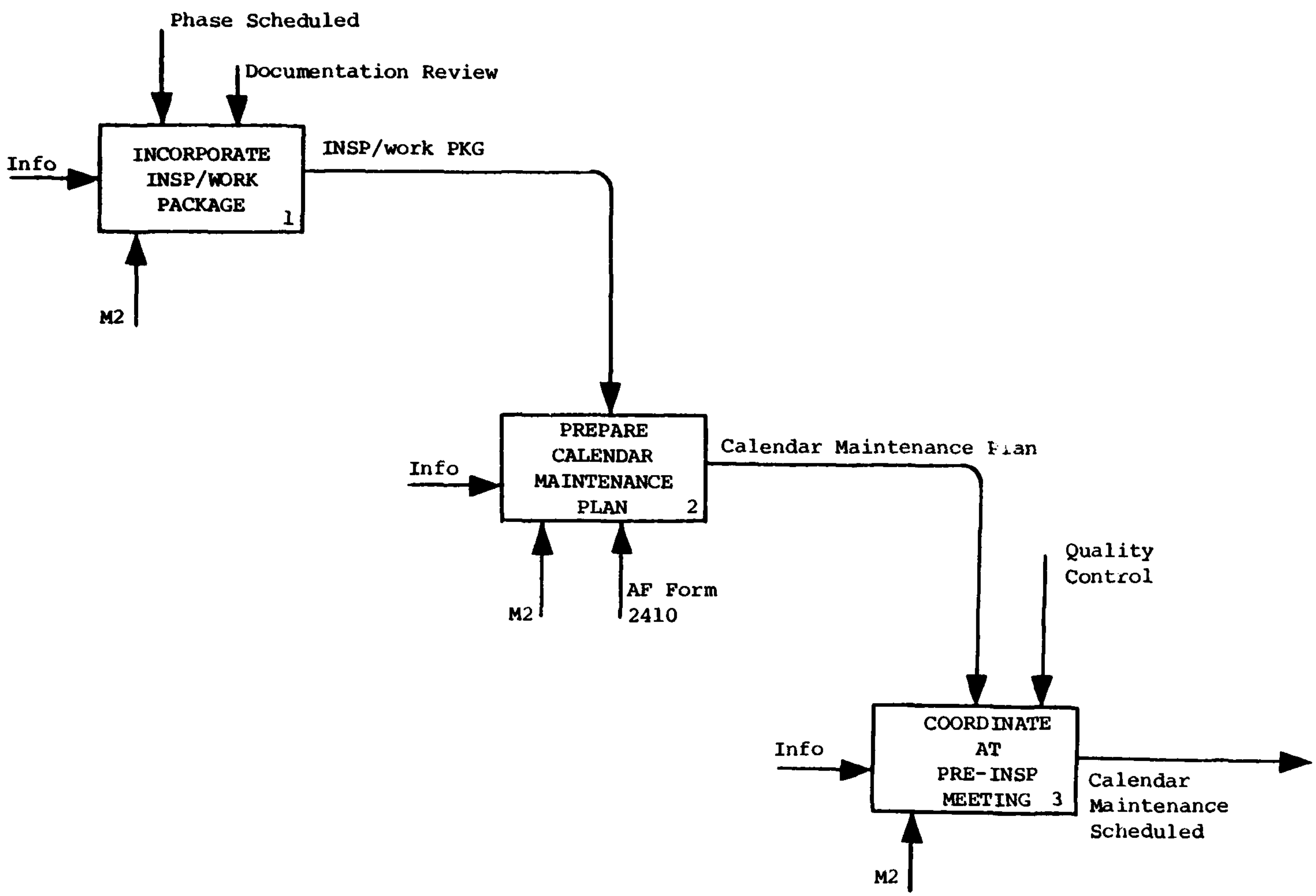


Fig. 4-18. Schedule Calendar Maintenance (A2223114)

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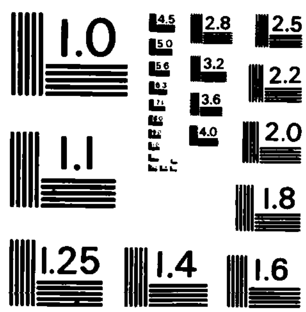

MICROCOPY RESOLUTION TEST CHART
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Corrosion Control

The decision process of scheduling corrosion control (Figure 4-19) involves: displaying aircraft due corrosion control, analyzing available aircraft that require corrosion control, and assigning an optimal aircraft from feasible candidates. When assigning an optimal aircraft (Figure 4-20) for corrosion control the scheduler compares feasible candidates, applies any tradeoffs, and selects the appropriate B-52 for corrosion control.

Model Application

It must be understood that the maintenance scheduling model which has been presented does not necessarily depict the exact decision process of any given scheduler. Maintenance schedulers vary in experience and judgement. A scheduler does not usually develop the optimal schedule, but settles for a workable plan which is acceptable to management. Instead, this model should be seen as generally applying to scheduling decisions as they are made in SAC wings assigned B-52H aircraft. The model is intended to describe the current decision process and can be used as the basis for formulation of normative models and a guide to the DSS design range for maintenance scheduling.

Chapter V details the overall perspective for the descriptive model. DSS implementation is also discussed, and suggestions are made for further research.

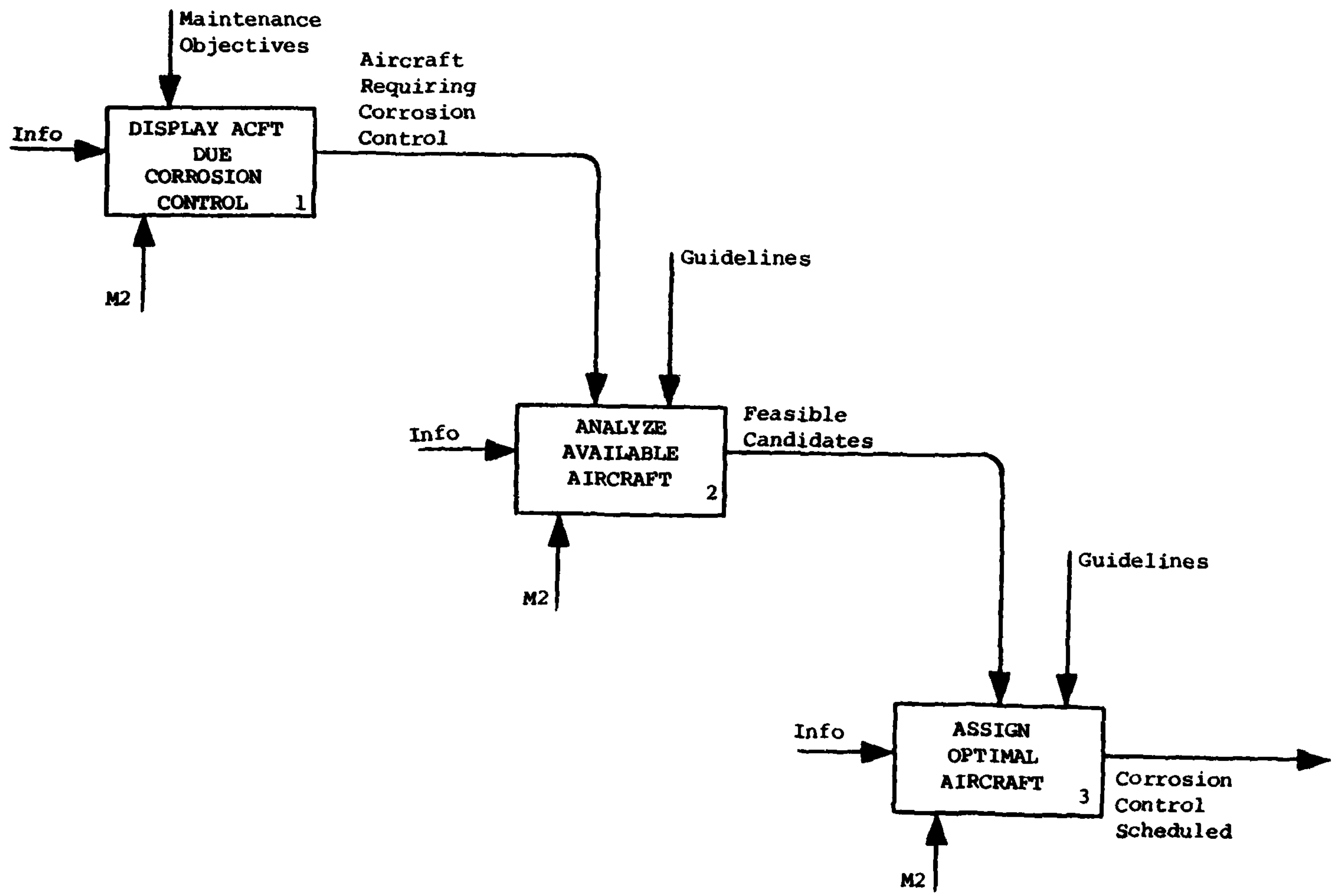


Fig. 4-19. Schedule Corrosion Control (A2223115)

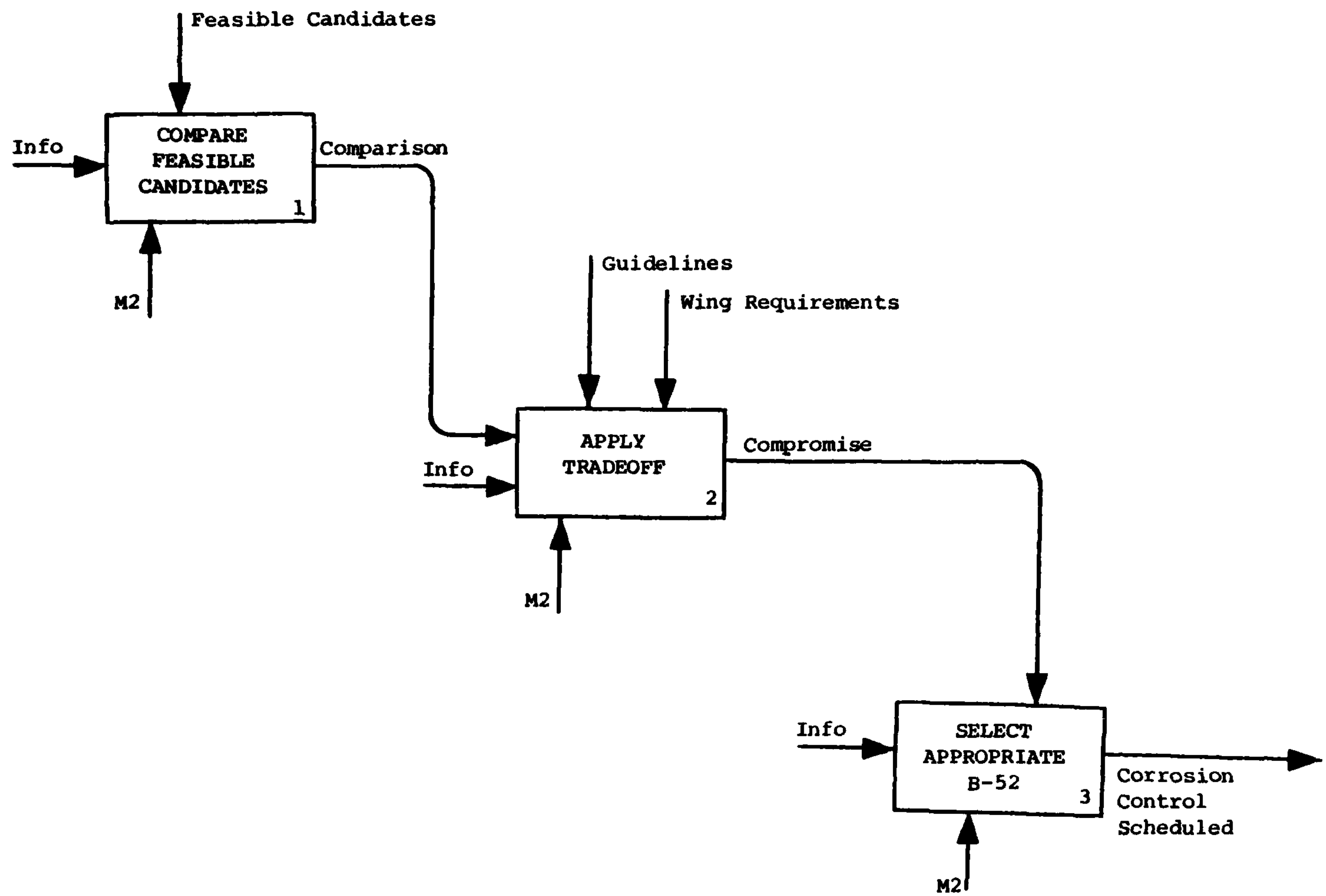


Fig. 4-20. Assign Optimal Aircraft (A22231153)

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Chapter IV presented a detailed functional model of the maintenance scheduling process. Using $IDEF_0$ methodology, the model defined several levels of increasing decision complexity in a hierarchical format. At the apex was a block identifying the context of the entire decision model; this was the planning process, of which maintenance scheduling is a subset.

The Mission Accomplishment Process

Now it is useful to view the context of the Chapter IV model in its larger framework, given in Figure 5-1. This framework is widely applicable within the Air Force, hence its title: the Mission Accomplishment Process. Planning the mission is Stage 2 of a four-stage ongoing process of mission accomplishment. The inputs and outputs of this planning stage are essentially identical to those of Figure 4-1. The information input is not shown since it applies to all four stages.

This treatment shows the maintenance scheduling process to be a model within models; it is a part of the planning stage of a system referred to here as the

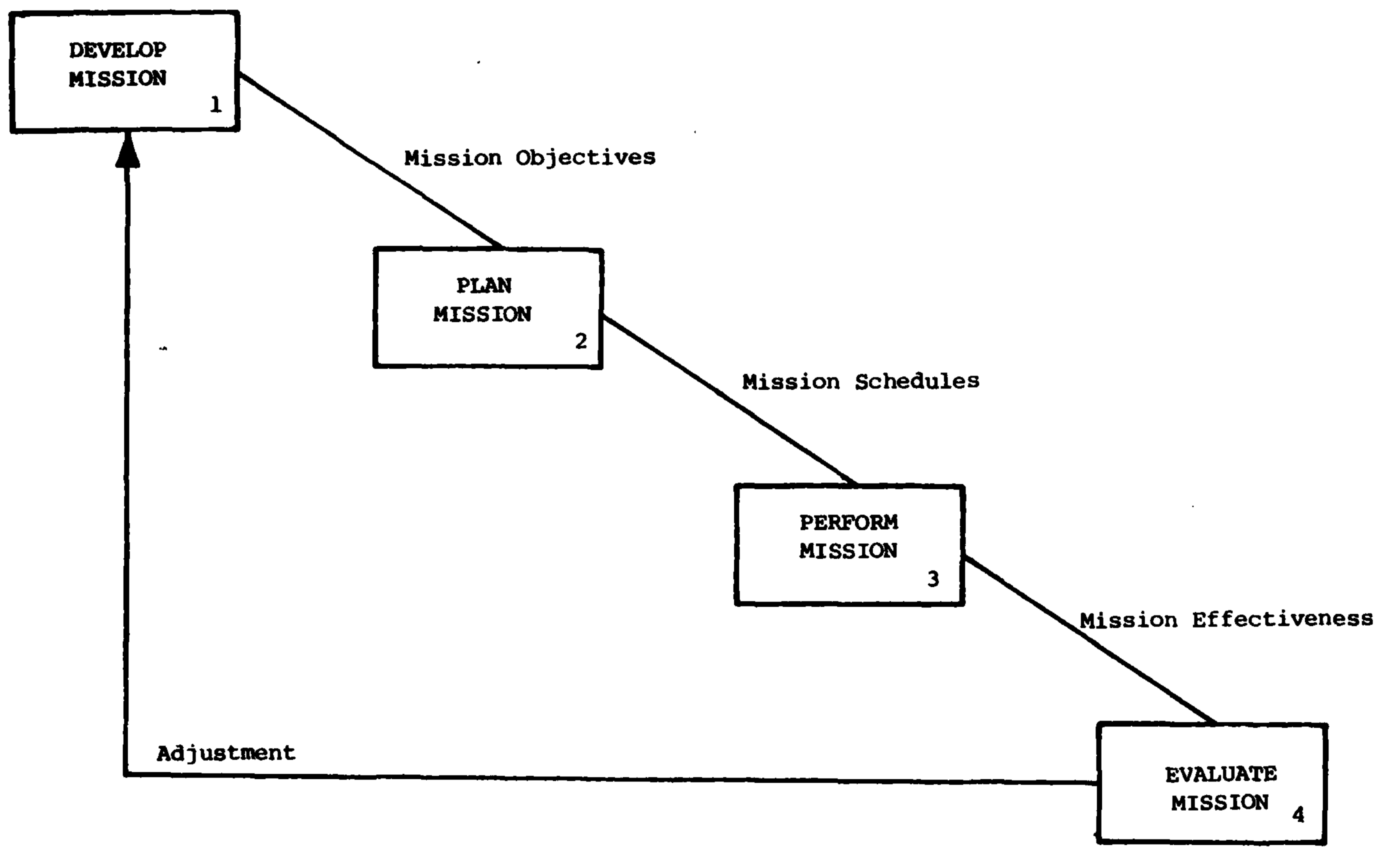


Fig. 5-1. The Mission Accomplishment Process

mission accomplishment process. Figure 5-1 greatly simplifies this process, but its essential characteristics are depicted.

DSS Implementation

The next step in the generation of a DSS for maintenance scheduling is to begin to implement the proposed system. It must be realized that design and implementation must proceed together after predesign has determined the scope of the problem.

> The predesign cycle is completed with the selection or synthesis of a specific design alternative [Figure 3-2 reflects synthesis: the definition of a range of choice] [Keen and Morton, 1978:176].

> There are basically two approaches to implementation based on the nature of user/analyst interaction. One approach, termed traditional, involves a minimum of user input, relying primarily on the analyst's expertise to assure appropriate problem conceptualization, model definition, and solution generation. The alternative strategy, termed evolutionary, attempts to maximize user input by beginning with simplistic models and iteratively updating these models based on feedback from actual usage by the client [Alavi and Henderson, 1981:1311].

In order to apply the evolutionary strategy, it is necessary to decide who will be the user. This thesis has been based on information available from the 28th Bombardment Wing, Ellsworth AFB, South Dakota. Since each SAC wing has its own peculiar scheduling techniques, not to mention the differing personalities and experience of the individual schedulers involved, initial implementation would involve a particular SAC wing. Once the initial

user has been identified, DSS implementation can proceed using the evolutionary strategy.

Since design and implementation are interwoven, before system design can progress, the user must be committed to change and must be actively involved in the evolutionary design process. "The manager's reality is the one in which implementation takes place; the technology to be used must be adapted to that context and not imposed on it [Keen and Morton, 1978:193]." Referring to Figure 3-3, once the functional model is revised and accepted by the user, the necessary data can be identified and collected for incorporation into the DSS data base. The model provides the framework for relevant data assimilation as well as being part of the context needed for design of the system processor. Therefore, further design and implementation must necessarily involve interaction between the user and the DSS designer.

Summary

Chapter I presented the problems inherent in the present nature of the aircraft maintenance scheduling process. The organizational structure of the Deputy Commander for Maintenance complex was outlined and the Operational Planning Cycle was discussed. Also included were recent studies concerning the application of computer technology to maintenance scheduling.

Chapter II provided background material on production scheduling techniques and a discussion of computer technology and Decision Support Systems. Also included were four objectives which this research was intended to accomplish.

Chapter III outlined the DSS design process and showed how such a design could be applicable to the aircraft maintenance scheduling problem. A plan for creating a descriptive functional model, as the first step of this design process, was presented. Following this, the modeling methodology, Integrated Computer-Aided Manufacturing, was chosen and the $IDEF_0$ system architecture was explained.

Chapter IV presented the maintenance scheduling model. It outlined a hierarchical representation of maintenance planning, scheduling, and resource allocation. Finally, the application of the model to the scheduling decision process was discussed.

Conclusions

The wing level scheduling decision process in SAC is a complex, interactive system. To facilitate the study of this system, four research objectives were identified in Chapter I.

Objective one was to define the structure of the maintenance scheduling process. This is accomplished in Chapter I through a thorough explanation of the agencies

and relationships involved under AFR 66-1 in the Strategic Air Command. Additionally, this structure is elaborated by the maintenance scheduling model in Chapter IV.

Objective two, identification of the decision processes involved in producing a monthly maintenance schedule, is accomplished by enumerating the maintenance factors involved in monthly scheduling and identifying their interactions and sequential constraints. This is accomplished in Chapter IV by breaking down the scheduling process into decision nodes with defined inputs and outputs.

Objective three was to construct a functional model which includes scheduling factors, relationships, and decision policies. The maintenance scheduling model constructed in Chapter IV fulfills this objective. $IDEF_0$, although specifically developed to model manufacturing companies, has been shown by this research application to lend itself to diverse functional modeling applications. The appropriateness of the $IDEF_0$ technology as the proper methodology for construction of the maintenance scheduling model is discussed in Chapter III.

Objective four was to show how this model could provide a means for establishment of a maintenance scheduling DSS. Chapter III shows how the DSS design process evolves, and relationships between the descriptive system model and the ideal normative models are identified. Also,

a specific DSS design for aircraft maintenance scheduling is presented; the functional model is identified as the first step toward an eventual working DSS.

Therefore, it is now possible to address the research question which forms the basis for this thesis effort: can a decision model of the maintenance scheduling process be constructed which will serve as a basis for a DSS which will support development of monthly aircraft maintenance planning? It has been shown that a functional model of the monthly B-52 aircraft maintenance scheduling process can be developed which defines and integrates the many diverse tasks involved. It has also been shown that a DSS for maintenance scheduling could result in an improvement in the effectiveness of the scheduling decision-making process. From the insight gained, the researchers are confident that the development of an informational model aimed at defining a data base to support the scheduler's efforts is achievable.

Recommendations

This research effort has provided the conceptual background and predesign study for a maintenance scheduling DSS. Future research should be guided toward development and implementation of a DSS using the following recommendations.

1. The function model ($IDEF_0$) presented in Chapter IV should be reviewed by the users to validate the model. This requires an extensive evaluation of the model to insure that it applies to the real-world system. As the users refine the model, its validity and therefore its value to the decision maker will increase.

2. The DSS data base should be defined. An information model ($IDEF_1$) could be developed to define this data base. $IDEF_1$ is a modeling methodology designed to produce an information model needed to support an $IDEF_0$ function model.

3. Decision modules should be developed which integrate decision logic and the data base. These decision modules can constitute the initial DSS implementation phase.

4. A dynamic system model ($IDEF_2$) should be developed to study the overall performance of the maintenance scheduling process. $IDEF_2$ is a modeling methodology designed to produce a dynamic model which represents the time varying behavior of functions, information, and resources. This dynamic model will further the evolution of the DSS application to the changing environment of aircraft maintenance scheduling.

5. A possible hypothesis that arises from the previous recommendations is: will the developed IDEF models provide a useful training and educational tool to

improve new schedulers' and maintenance managers' scheduling techniques?

In the maintenance environment at Ellsworth AFB, schedulers and other maintenance managers interface daily. The information exchange could be improved if the personnel involved had a common mechanism to facilitate interaction. The developed IDEF models could provide this common communication tool. By involving all concerned managers in the scheduling process, the models can be refined and kept current.

Although the model which has been developed applies only to aircraft scheduling in SAC, eventually an integrated system of models from all Major Commands could be modified by the Air Training Command (ATC) to provide a common core of course material. Currently the course taught at the Chanute Technical Training Center provides the student with entry level knowledge of maintenance management skills and scheduling abilities. The ATC modified IDEF function and information models could possibly be helpful in bringing these new schedulers to a common level of maintenance awareness. From this level, the $IDEF_2$ dynamic model could be introduced into the course curriculum to provide the schedulers with increasing complexity until their training reaches a real-world state. This would enhance the schedulers' training by allowing them to

learn and improve their scheduling techniques on a gradient scale.

6. The function model should be expanded to include the development of models for weekly scheduling and daily expediting.

7. A parallel $IDEF_0$ function model should be developed to encompass the 28th Air Refueling Squadron at Ellsworth AFB. This tanker (KC-135 aircraft) scheduling model should also undergo user review for validation and have its data base defined, before proceeding with a dynamic model.

8. An integrated system of models should be developed for both bomber and tanker maintenance scheduling to produce a total aircraft wing maintenance scheduling model. This system would be of value for those SAC aircraft wings that have both B-52 and KC-135 aircraft squadrons assigned to the same base, with a classic alert mission commitment.

9. Maintenance scheduling $IDEF_0$ function models should be developed for similar SAC aircraft wings to test the transference of the models.

10. Maintenance scheduling $IDEF_0$ function models should be developed for dissimilar SAC aircraft wings. For example, there are various combinations of B-52, KC-135, RC-135, FB-111, SR-71 and U-2 aircraft, with associated missions.

11. The performance of similar SAC aircraft wings should be compared between those units using DSS and those not (e.g., do the results justify the effort?).

12. The decision process in other logistics disciplines, which could profitably benefit from the application of a Decision Support System, should be pursued.

Toward an Operational DSS

In order for further research to add to the body of knowledge previously discussed, the researcher should remember that the primary aim is to improve maintenance scheduling and to determine if the application of a DSS would contribute to this improvement. Future research should involve the user in the evolutionary design and initial implementation phases of DSS development.

> In the predesign stage, objectives are fairly broad and commitments and expectations are general. These now need to be . . . [defined] . . . very precisely since they constitute the main criteria for the constraints on the formal design [Keen and Morton, 1978:180].

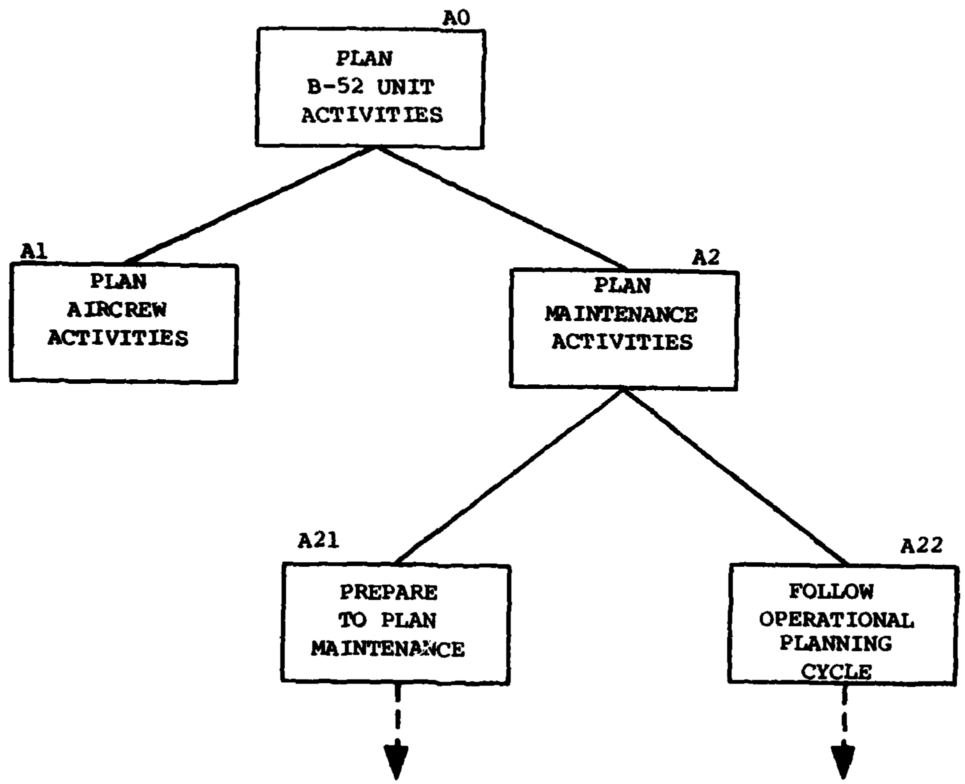
Hopefully this research will be the beginning in a continuing series of efforts that will result in developing a real working Decision Support System to improve aircraft maintenance scheduling.

APPENDIX

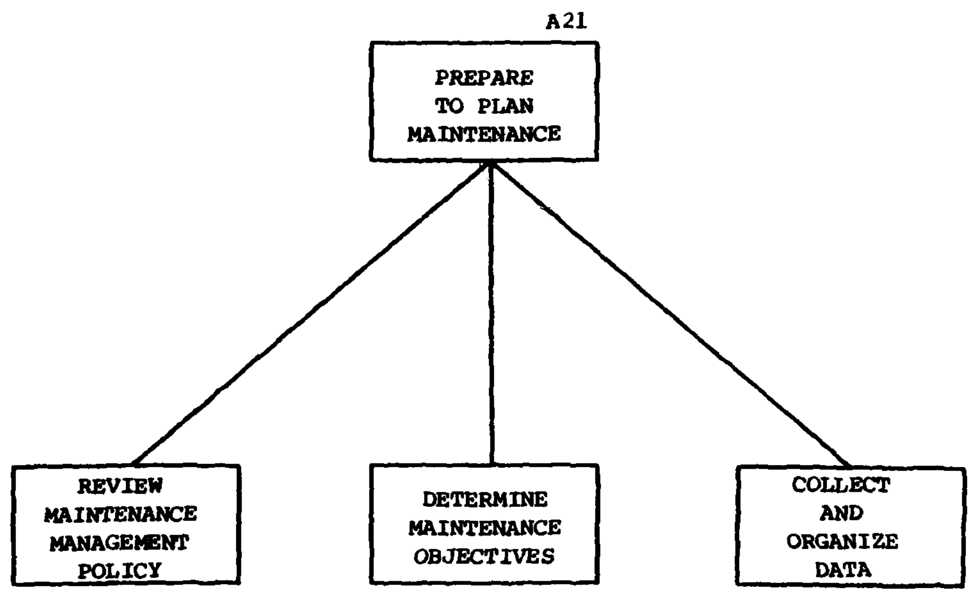
NODE TREE

This appendix contains a node tree, which graphically displays an overall view of the parent module and the structure of its subfunctions. The parent module and some of its subfunctions that pertain to aircraft maintenance scheduling are examined more closely in Chapter IV.

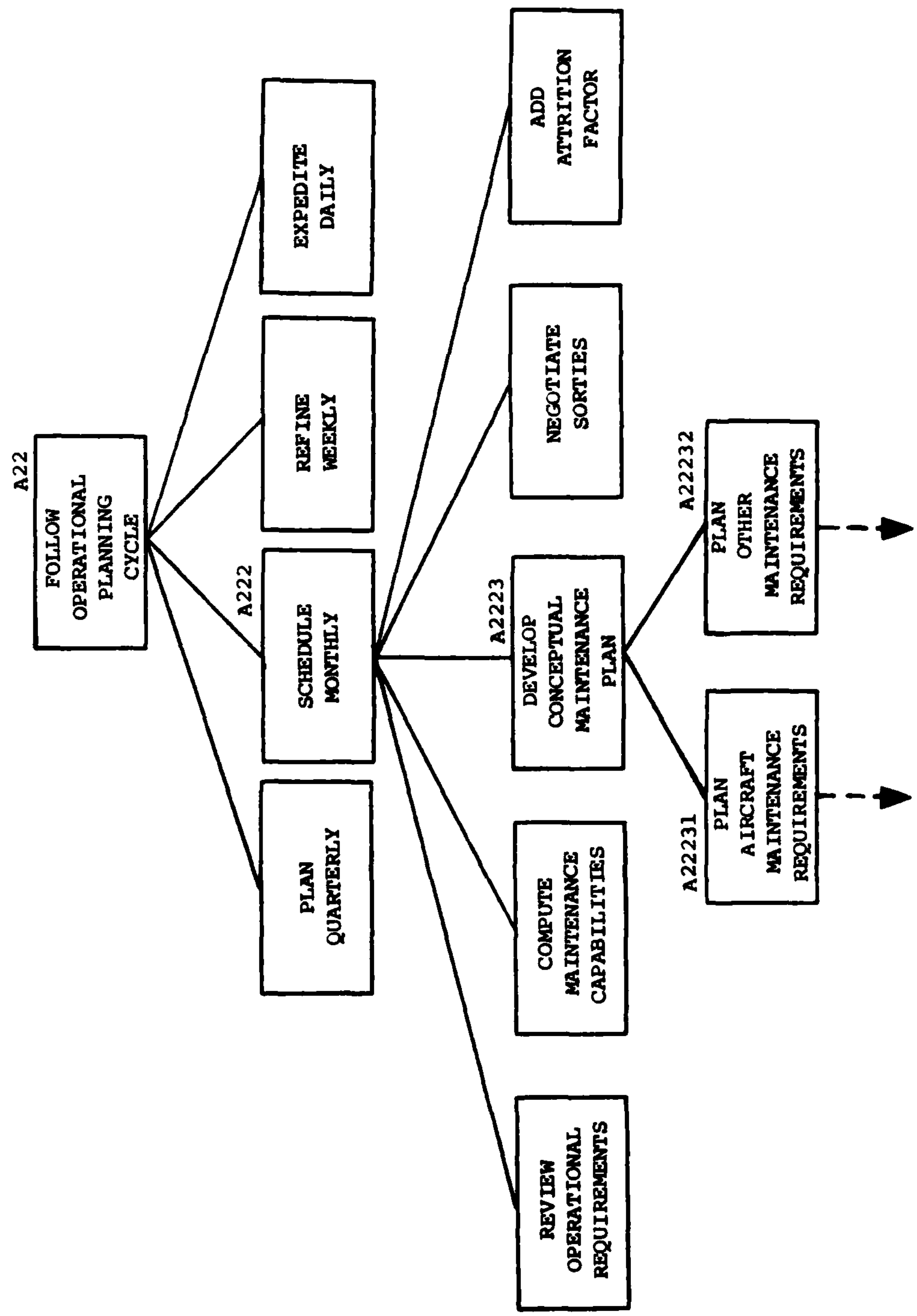
Due to its size and reproduction constraints, the node tree is displayed a few levels per page in descending order. Wherever a module has a dashed line and arrowhead, that function will be further subdivided.


A0
PLAN
B-52 UNIT
ACTIVITIES
A1
PLAN
AIRCREW
ACTIVITIES
A2
PLAN
MAINTENANCE
ACTIVITIES
A21
PREPARE
TO PLAN
MAINTENANCE
A22
FOLLOW
OPERATIONAL
PLANNING
CYCLE

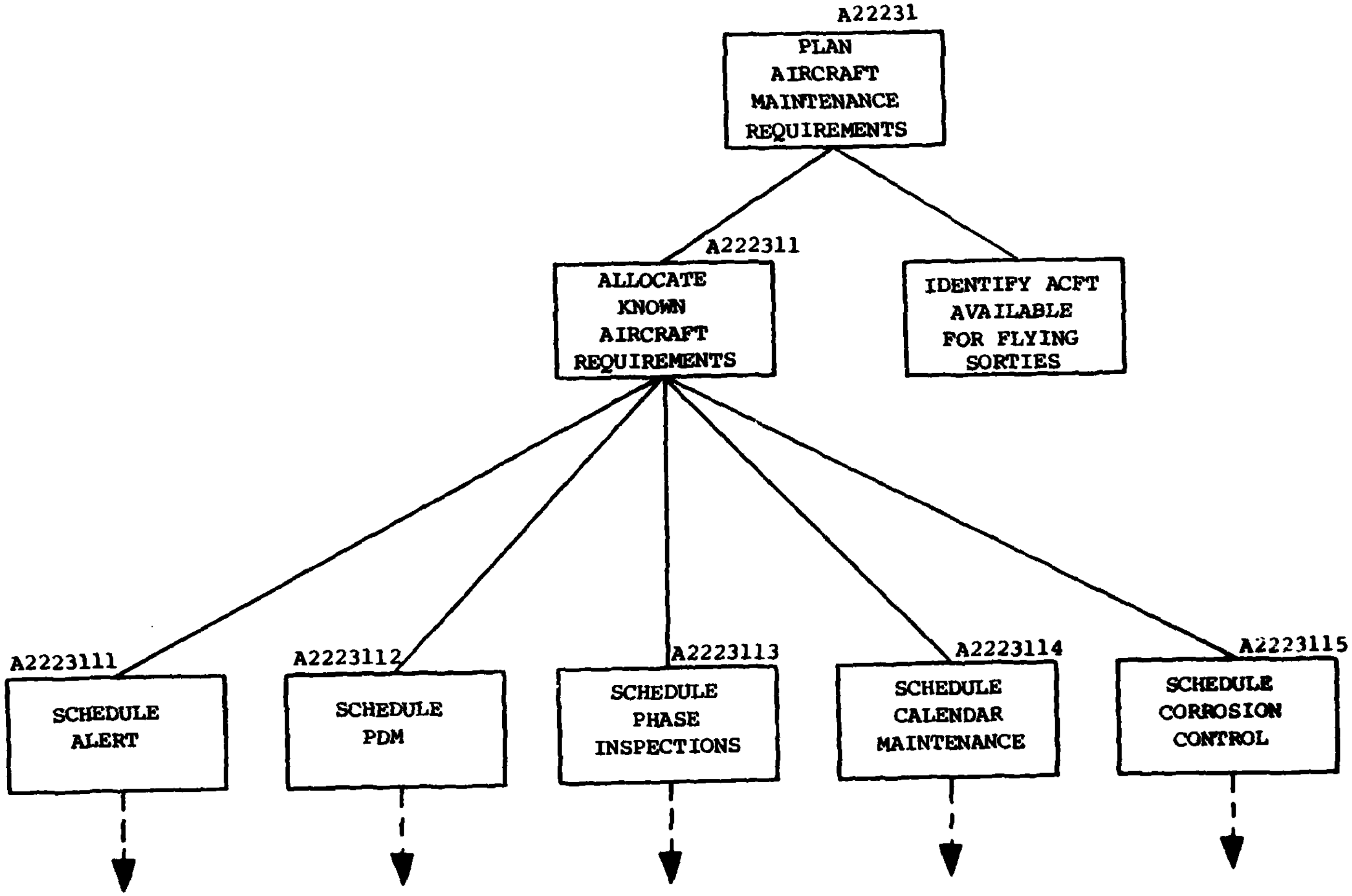
Levels 0-2


A21
PREPARE TO PLAN MAINTENANCE
REVIEW MAINTENANCE MANAGEMENT POLICY
DETERMINE MAINTENANCE OBJECTIVES
COLLECT AND ORGANIZE DATA

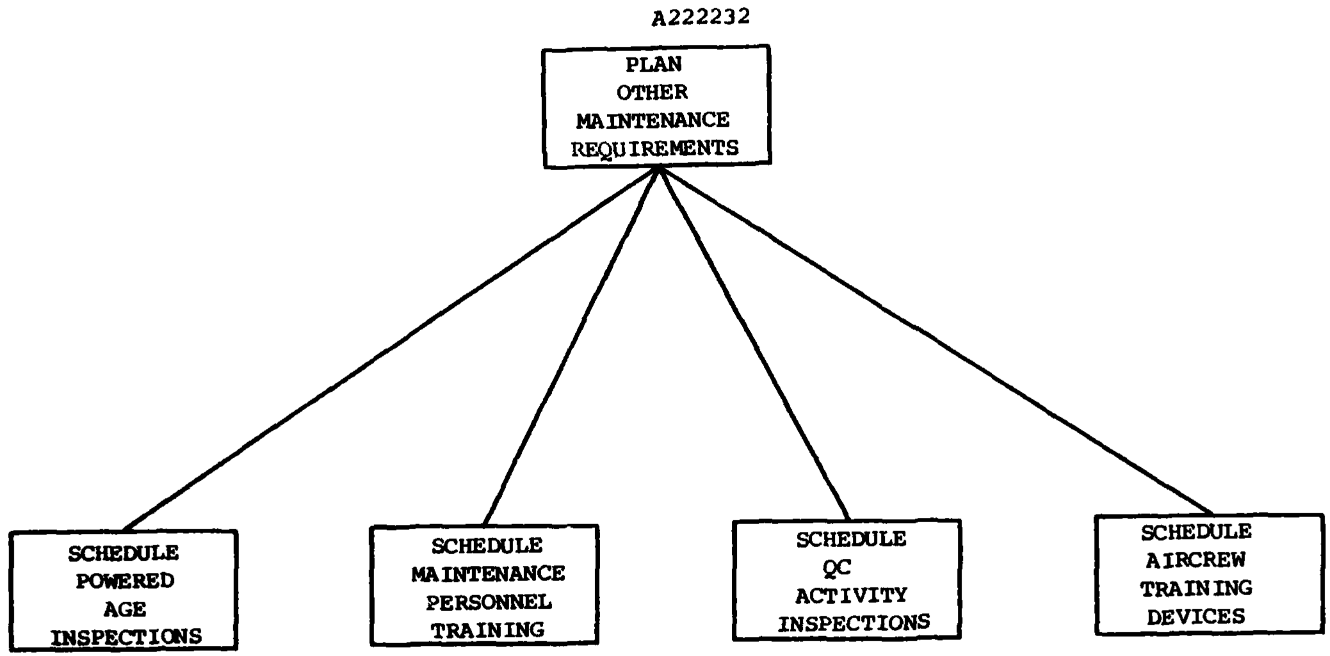
Levels 2-3


A22
FOLLOW OPERATIONAL PLANNING CYCLE
PLAN QUARTERLY
A222
SCHEDULE MONTHLY
REFINE WEEKLY
EXPEDITE DAILY
REVIEW OPERATIONAL REQUIREMENTS
COMPUTE MAINTENANCE CAPABILITIES
A2223
DEVELOP CONCEPTUAL MAINTENANCE PLAN
NEGOTIATE SORTIES
ADD ATTRITION FACTOR
A22231
PLAN AIRCRAFT MAINTENANCE REQUIREMENTS
A22232
PLAN OTHER MAINTENANCE REQUIREMENTS

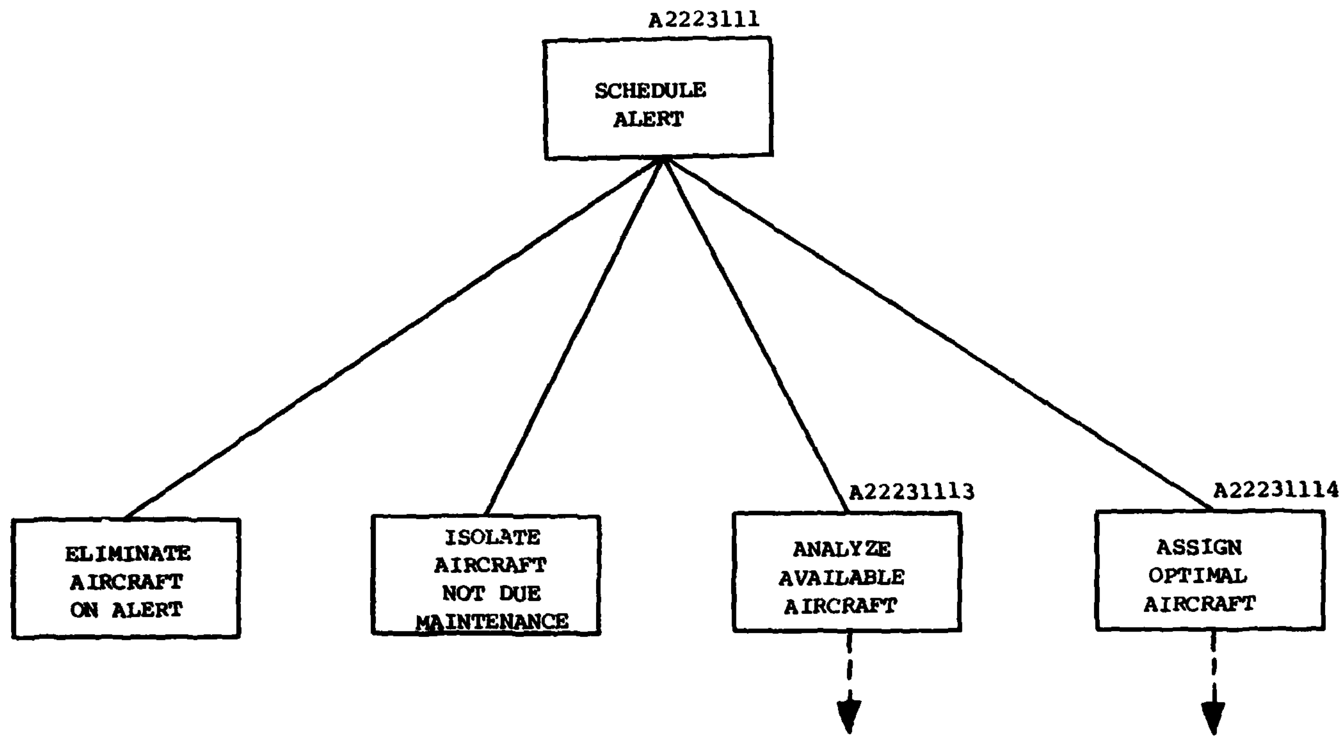
Levels 2-5


A22231
PLAN AIRCRAFT MAINTENANCE REQUIREMENTS
A222311
ALLOCATE KNOWN AIRCRAFT REQUIREMENTS
IDENTIFY ACFT AVAILABLE FOR FLYING SORTIES
A2223111
SCHEDULE ALERT
A2223112
SCHEDULE PDM
A2223113
SCHEDULE PHASE INSPECTIONS
A2223114
SCHEDULE CALENDAR MAINTENANCE
A2223115
SCHEDULE CORROSION CONTROL

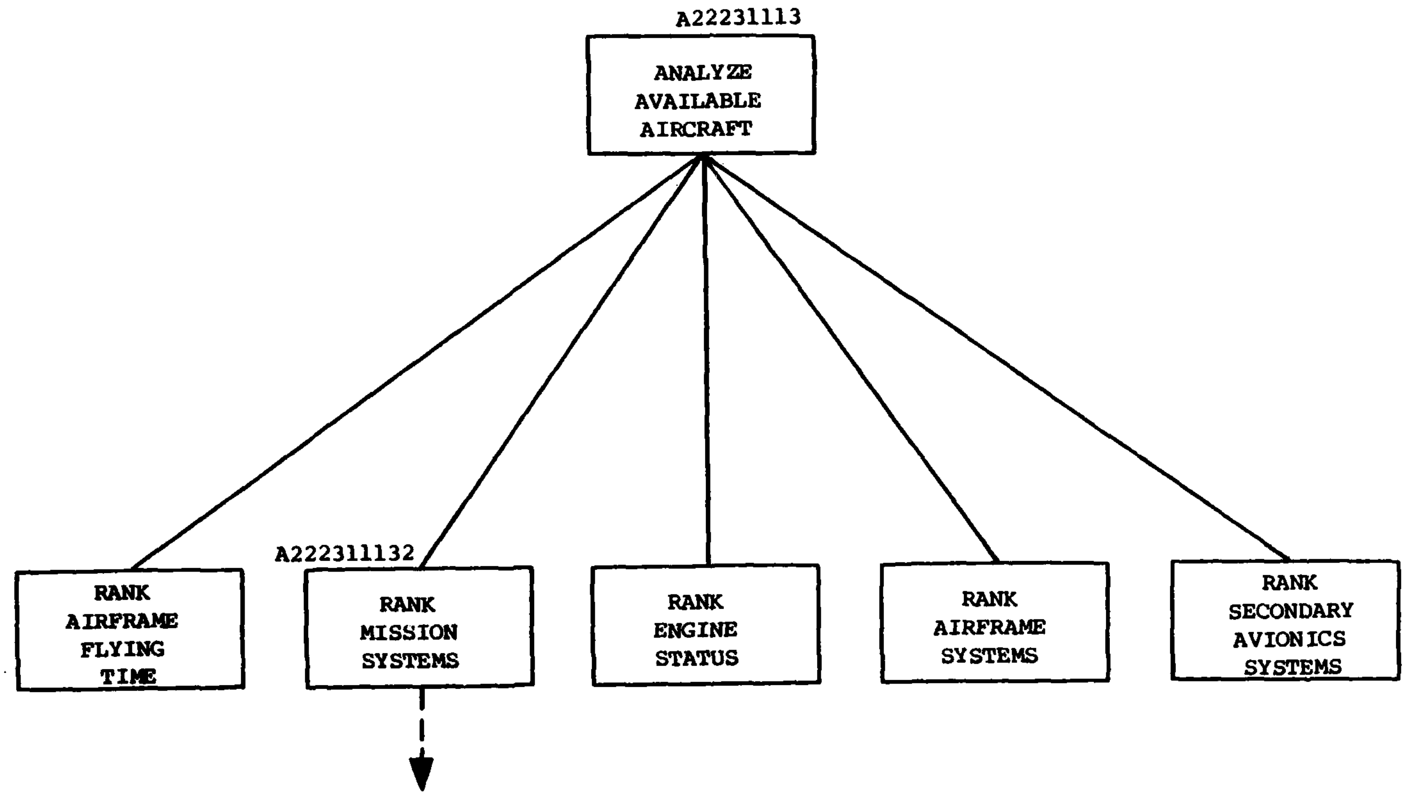
Levels 5-7


A222232
PLAN
OTHER
MAINTENANCE
REQUIREMENTS
SCHEDULE
POWERED
AGE
INSPECTIONS
SCHEDULE
MAINTENANCE
PERSONNEL
TRAINING
SCHEDULE
QC
ACTIVITY
INSPECTIONS
SCHEDULE
AIRCREW
TRAINING
DEVICES

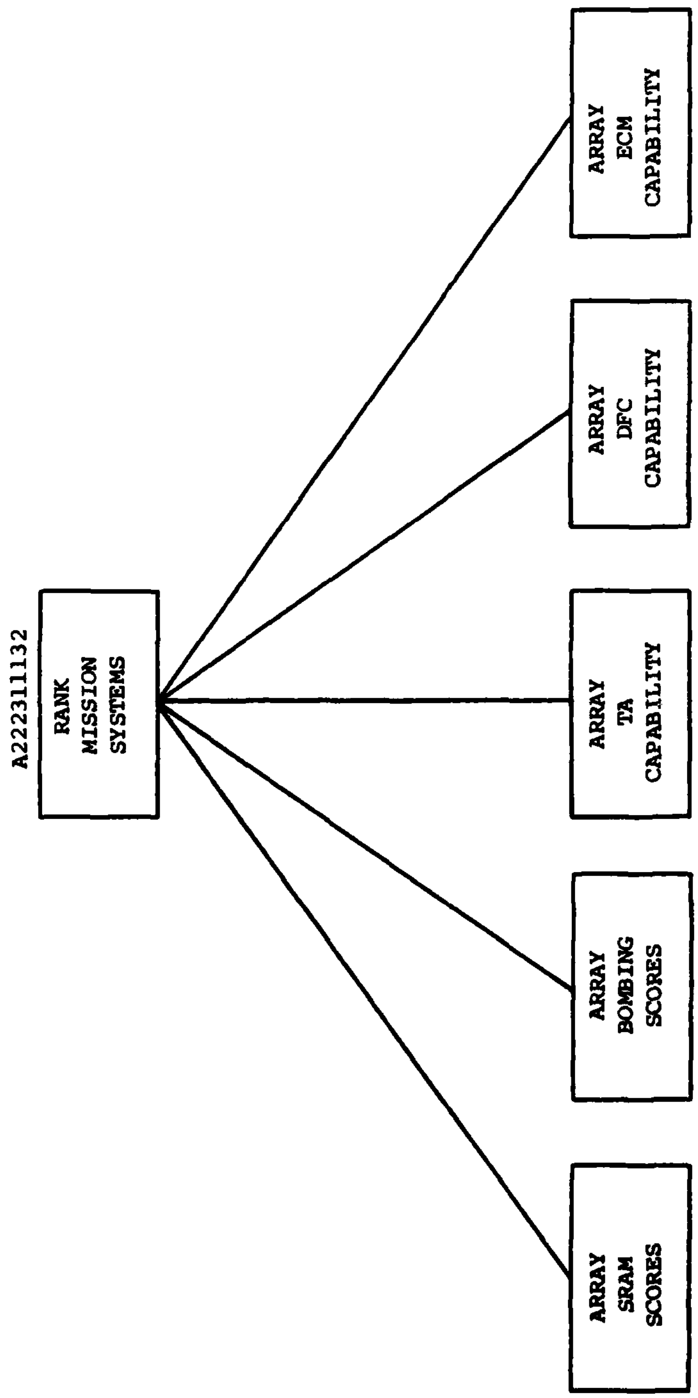
Levels 5-6


A2223111
SCHEDULE ALERT
ELIMINATE AIRCRAFT ON ALERT
ISOLATE AIRCRAFT NOT DUE MAINTENANCE
A22231113
ANALYZE AVAILABLE AIRCRAFT
A22231114
ASSIGN OPTIMAL AIRCRAFT

Levels 7-8


A22231113
ANALYZE AVAILABLE AIRCRAFT
RANK AIRFRAME FLYING TIME
A222311132
RANK MISSION SYSTEMS
RANK ENGINE STATUS
RANK AIRFRAME SYSTEMS
RANK SECONDARY AVIONICS SYSTEMS

Levels 8-9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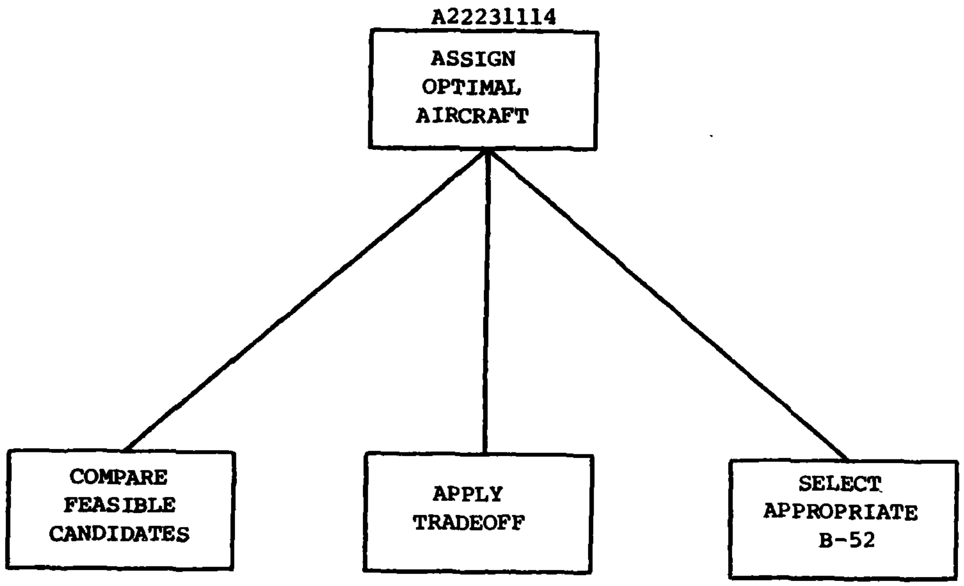
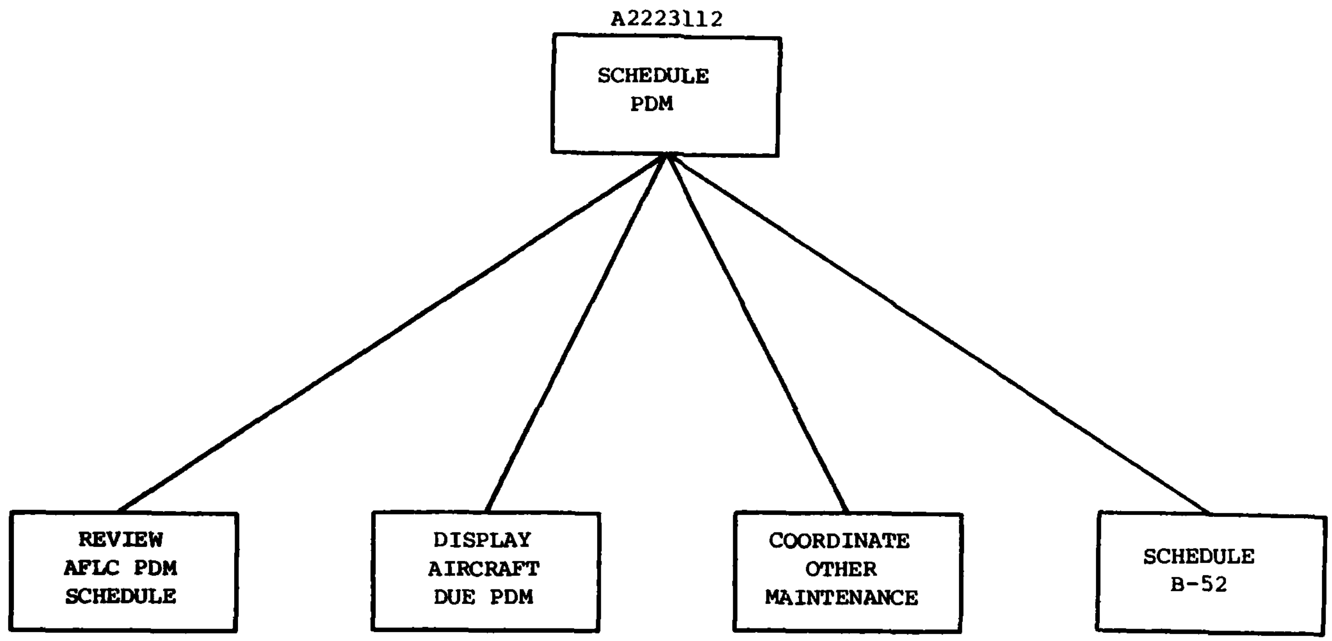
RANK MISSION SYSTEMS
ARRAY SRAM SCORES
ARRAY BOMBING SCORES
ARRAY TA CAPABILITY
ARRAY DFC CAPABILITY
ARRAY ECM CAPABILITY

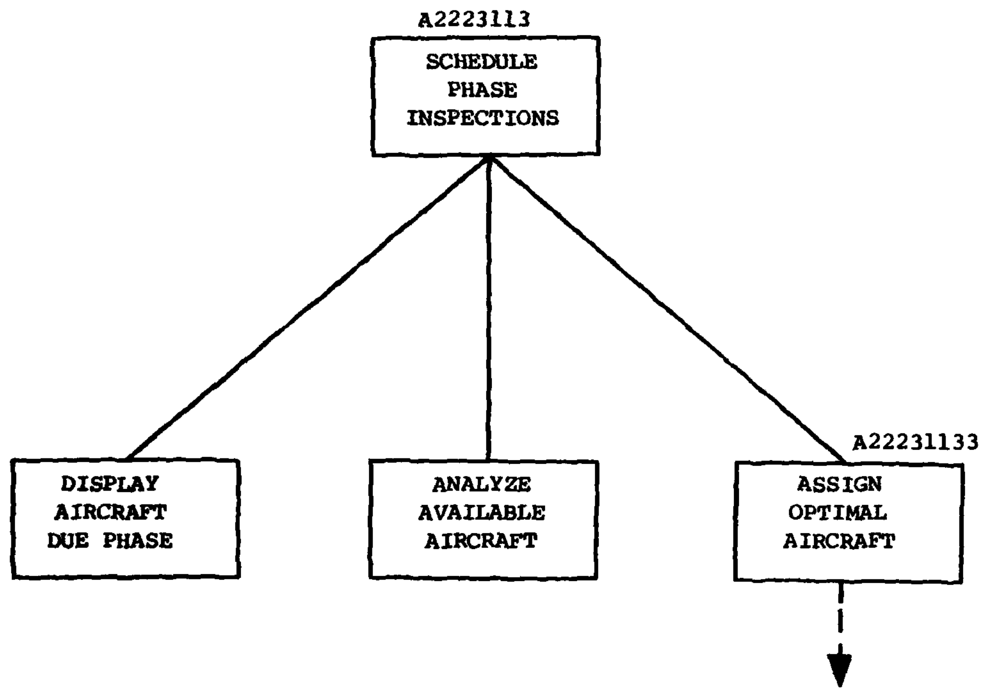
Levels 9-10


A22231114
ASSIGN OPTIMAL AIRCRAFT
COMPARE FEASIBLE CANDIDATES
APPLY TRADEOFF
SELECT APPROPRIATE B-52

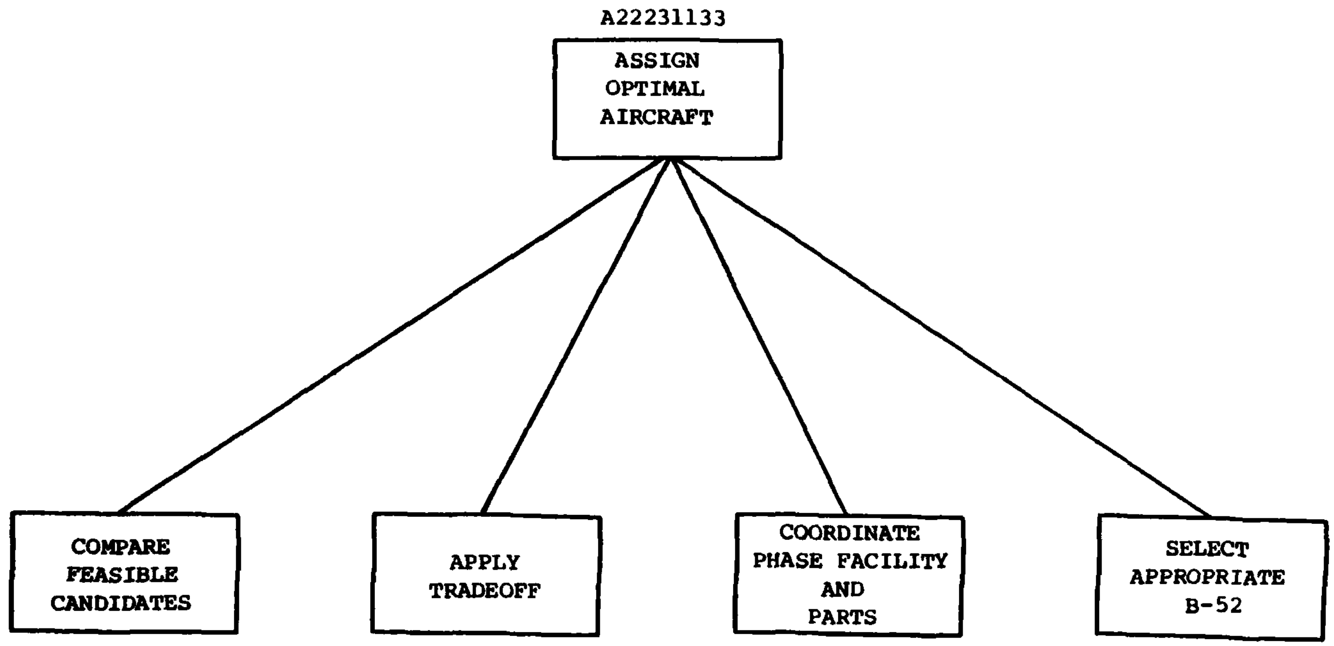
Levels 8-9


A2223112
SCHEDULE PDM
REVIEW AFLC PDM SCHEDULE
DISPLAY AIRCRAFT DUE PDM
COORDINATE OTHER MAINTENANCE
SCHEDULE B-52

Levels 7-8

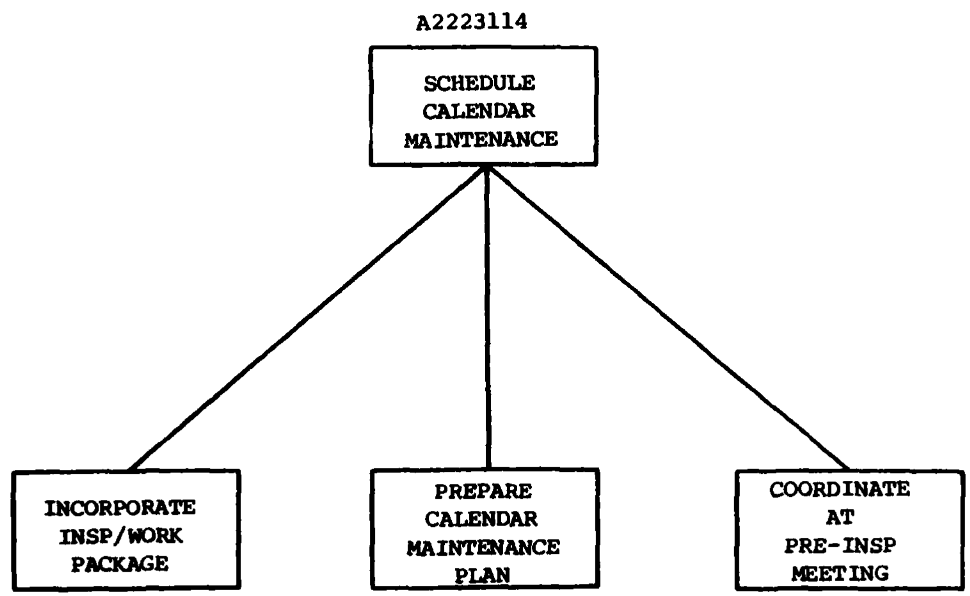

A2223113
SCHEDULE
PHASE
INSPECTIONS
DISPLAY
AIRCRAFT
DUE PHASE
ANALYZE
AVAILABLE
AIRCRAFT
A22231133
ASSIGN
OPTIMAL
AIRCRAFT

Levels 7-8

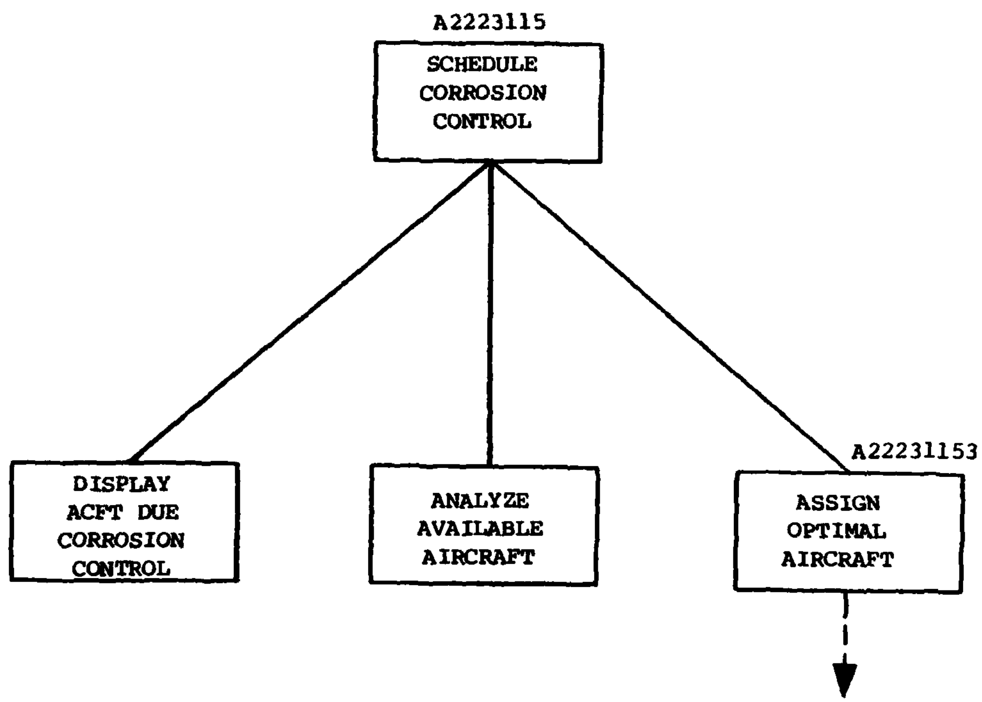


A22231133
ASSIGN OPTIMAL AIRCRAFT
COMPARE FEASIBLE CANDIDATES
APPLY TRADEOFF
COORDINATE PHASE FACILITY AND PARTS
SELECT APPROPRIATE B-52

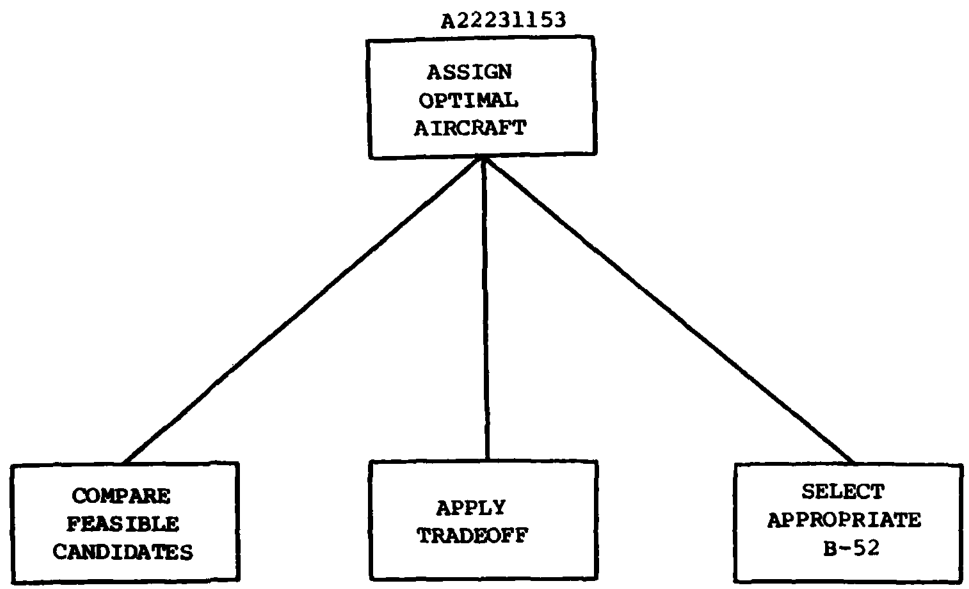
Levels 8-9


A2223114
SCHEDULE CALENDAR MAINTENANCE
INCORPORATE INSP/WORK PACKAGE
PREPARE CALENDAR MAINTENANCE PLAN
COORDINATE AT PRE-INSP MEETING

Levels 7-8


A2223115
SCHEDULE
CORROSION
CONTROL
DISPLAY
ACFT DUE
CORROSION
CONTROL
ANALYZE
AVAILABLE
AIRCRAFT
A22231153
ASSIGN
OPTIMAL
AIRCRAFT

Levels 7-8


A22231153
ASSIGN OPTIMAL AIRCRAFT
COMPARE FEASIBLE CANDIDATES
APPLY TRADEOFF
SELECT APPROPRIATE B-52

Levels 8-9

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